

Open Research Online

The Open University's repository of research publications and other research outputs

A national method for predicting environmental pollution

Thesis

How to cite:

Baverstock, Suzie Jane (1989). A national method for predicting environmental pollution. PhD thesis The Open University.

For guidance on citations see [FAQs](#).

© 1989 The Author



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

Version: Version of Record

Link(s) to article on publisher's website:

<http://dx.doi.org/doi:10.21954/ou.ro.0000decc>

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data [policy](#) on reuse of materials please consult the policies page.

oro.open.ac.uk

DX 89240

UNRESTRICTED

A National Method for Predicting Environmental Pollution

Thesis submitted by:

Suzie Jane Baverstock

for the degree of

Doctor of Philosophy

November 1988

Department of Engineering Mechanics

Faculty of Technology

Open University

Milton Keynes

England

Author's number : M7021591

Date of submission : 20th December 1988

Date of award : 5th December 1989

HIGHER DEGREES OFFICE
LIBRARY AUTHORISATION FORM

STUDENT: SUZIE S. BAVERSTOCK SERIAL NO: M7021591

DEGREE: PHD

TITLE OF THESIS: A National Method for Predicting
Groundwater Pollution

I confirm that I am willing that my thesis be made available to readers
and maybe photocopied, subject to the discretion of the Librarian.

SIGNED: Suzie S. Baverstock DATE: 21.11.88

Abstract

Area based prediction methods are developed for the noise indices L_{Aeq} , L_{A10} and L_{A90} and winter and annual measures of sulphur dioxide air pollution concentrations. The research examines the relationships between these pollutant variables and a number of key demographic predictor variables. The demographic variables considered include:

- traffic density,
- road network density and
- land use

for predicting noise and,

- land use and
- whether an area is subject to smoke control

for predicting sulphur dioxide concentrations.

Data from the National Survey of Smoke and Sulphur Dioxide, a noise survey of Milton Keynes, Bexley and the West Midland regions and noise data supplied by Open University undergraduate students studying the course T234 'Environmental Control and Public Health' have been used to calibrate and test the proposed theoretical prediction models partially. Two forms of prediction model are presented namely prediction matrices and linear multivariate regression models.

The main findings of the research are:

1. That L_{Aeq} , L_{A10} and L_{A90} can be predicted using industrial land use and traffic density but there are regional differences in noise which are unaccounted for by these variables
2. That the variability of noise ($L_{A10} - L_{A90}$) is related to traffic density

3. Measures of sulphur dioxide are related to both land use and whether an area is subject to a smoke control order and there are no significant regional differences unaccounted for by these predictor variables (East Anglia excluded). Regression equations are presented which predict sulphur dioxide concentrations with accuracies of between $\pm 1.84 \mu\text{g}/\text{m}^3$ and $\pm 4.36 \mu\text{g}/\text{m}^3$. However, the results from the detailed study of the Midland, North East and North West regions indicate that there is an interaction between the region and smoke control variables.
4. The ratio of $\frac{\text{Smoke}}{\text{SO}_2}$ is related to whether or not an area is subject to smoke control.

Acknowledgements

I would like to thank my supervisors Dr. Keith Attenborough of the Open University and Dr. Robert L. Pocock of Midland Environment Ltd. for their invaluable support, advice and encouragement throughout these studies.

I am grateful to the Open University who were the sole sponsors for this research and to the T234 'Environmental Control and Public Health' course team and students for supplying me with the national noise data used in this thesis. I am also grateful to Warren spring laboratory for the use of their summary air pollution statistics, and to the Greater London Council, West Midland Metropolitan County Council, London Borough of Bexley Council, Buckinghamshire County Council and Milton Keynes Development Corporation for their land use and traffic flow data.

Thanks are also given to my many friends and colleagues at the Open University and at W.S. Atkins and Partners for their help. Special thanks are given to Mr. James Paul for his statistical advice and to Dr. Jeanette Brooks for her friendship and for the many other ways in which she has helped me throughout this research.

Many thanks to my parents, Edward and Jean Baverstock, for all there support and encouragement throughout my studies.

Finally I would like to thank Earl Barr for his tremendous support and patience during the production of this thesis.

Contents

1	The Research Context	1
1.1	Introduction	1
1.2	Need for the Research	1
1.3	Considerations of Measurement and Prediction Techniques . .	4
1.4	The Potential of Area-based Methods of Prediction	5
1.5	Basic Hypothesis for Area-based Studies	9
1.6	Aims and Objectives of the Research	10
1.7	Research Demands and Constraints	10
1.8	Structure of the Thesis	11
2	Literature Review	13
2.1	Introduction	13
2.2	Evaluation of Area-based Methods of Noise Prediction	14
2.2.1	Area-type Classifications	15
2.2.2	Prediction Model Structures	19
2.2.3	Calibration of the Predictive Models	21
2.2.4	Model Performance	24
2.3	Evaluation of Area-type Classifications Used to Present Noise Pollution Data	26
2.3.1	The London Noise Survey.	27
2.3.2	The 1972 West Midlands Background Noise Survey . .	31
2.3.3	Survey of Noise Outside Homes in England	31
2.4	Conclusions from the Review of Noise Prediction Models . . .	32
2.5	Evaluation of Area-based Methods of Predicting Air Pollutants	35

2.6	Evaluation of Area-type Classifications Used to Present Air Pollution Data	43
2.7	Summary and Conclusions from the Air Pollution Prediction Model Literature Review.	52
3	Experimental Design	53
3.1	Selection of Pollutants	53
3.1.1	Selection of Noise Indices for Prediction	55
3.1.2	Selection of Air Pollutants for Prediction	58
3.1.3	Selection of Measures of Smoke and Sulphur Dioxide for Prediction	60
3.2	Construction of Theoretical Prediction Model for Noise Pollution	62
3.2.1	Selection of a Spatial Scale of Prediction for Noise Pollution	64
3.2.2	Selection of Noise Predictor Variables	68
3.2.3	Noise Prediction Model Design	70
3.2.4	Definition of Noise Model Land Use Categories	70
3.2.5	Specification of Noise Model Land Use Categories	72
3.2.6	Definition of Noise-model Vehicle Density Axis	74
3.3	Construction of Theoretical Prediction Model for Air Pollution	75
3.3.1	Selection of a Spatial Scale for Air Pollution Prediction	77
3.3.2	Selection of Predictors of Air Pollution	78
3.3.3	Air Pollution Prediction Model Design	84
3.3.4	Definition of Air Pollution Model Land Use Categories	84
3.3.5	The Theoretical Air Pollution Prediction Model	86
3.4	Validation of the Theoretical Models	86
3.4.1	Partial Testing of the Noise Prediction Model	86
3.4.2	Partial Testing of Air Pollution Model	93
3.4.3	Selection of Regional Areas	95
3.5	Resulting Hypotheses	96
3.5.1	General Hypotheses	96
3.5.2	Noise Hypotheses	98

4	Design of Field Measurements	100
4.1	Introduction	100
4.2	Noise Survey Objectives	100
4.3	Collection of Demographic Data	100
4.3.1	Land Use Data	101
4.3.2	Vehicle Flow Data	103
4.4	Characterisation of Grid Squares	104
4.4.1	Tolerable Error	104
4.4.2	Land Use Characterisation	106
4.4.3	Sources of Error in Land Use Characterisation	107
4.4.4	Vehicle Density Characterisation	108
4.5	Sample Area Selection	111
4.5.1	Grouping of Sample Squares into Cells of the Matrix	111
4.5.2	Number of Sample Squares Required to Calibrate Each of the Area-type Categories	112
4.5.3	Required Distribution of Selected Sample Squares, Within Each Matrix Cell, Across the Case-study Areas	112
4.6	Noise Survey Methodology	113
4.6.1	Survey Period	114
4.6.2	Sampling Density	115
4.6.3	Location of Measurement Positions	115
4.6.4	Site Measurement Method	116
4.6.5	Equipment	118
4.6.6	Pilot Noise Survey	119
4.6.7	Summary of Survey Method	121
5	Summary of Noise Model Calibration Data	125
5.1	Summary of Noise Survey	125
5.1.1	Duration of Noise Survey	125
5.1.2	Sample Size	125
5.1.3	Spatial Distribution of Sample Squares Surveyed	128
5.2	Wind Speed Correction Factor	128
5.2.1	Pococks Wind Correction Model	128

5.2.2	Validation of Pocock's Wind Correction Model for Na- tional Application	133
5.2.3	Time Weighting Sound Level Meter Setting	136
5.2.4	Temporal Variation in Noise Levels	137
5.3	Averaging Statistic Selection	139
5.3.1	Logarithmic Versus Arithmetic Averages	139
5.3.2	Characteristics of the Arithmetic Mean, Median and Mode as Averaging Statistics.	140
5.4	Measurement Distribution in Each Sample Square	144
5.5	Measurement Distributions in Each of the Prediction Matrix Cells	146
5.6	Arithmetic Means of Mean Measurements Within Each of the Prediction Matrix Cells	149
5.7	Arithmetic Means of Median Measurements Within Each of the Prediction Matrix Cells	154
6	The Statistical Testing of the Research Hypotheses Relating to Noise	159
6.1	Introduction	159
6.2	Testing of General Hypothesis 1 - Noise	159
6.2.1	Analysis of the Theoretical Noise Prediction Matrix .	160
6.2.2	Matrix Cell Selection Criteria for Inclusion in the Analysis of Variance Testing of the Prediction Matrix Model	161
6.2.3	Results from the Analysis of Variance Testing of the Prediction Matrix Using the Three Case Study Area Data	163
6.2.4	Results of the Analysis of Variance Testing of the Pre- diction Matrix Using the Student Data	166
6.2.5	Further Testing of the Prediction Matrix Structure . .	168
6.2.6	Testing of General Hypothesis 1 Using Regression Anal- ysis - Noise	172
6.2.7	The Theoretical Regression Model	173

6.2.8	Correlations Between the Un-transformed and Exponential Indices and the Demographic Variables	176
6.2.9	Results from the Regression Analysis of the Noise and Land Use Data from the Three Case Study Areas . . .	178
6.2.10	Results from the Regression Analysis of the Student Noise Measurements and Demographic Data	182
6.3	Testing of General Hypothesis 2 - Noise.	187
6.3.1	Test for 'Parallelism' in the Regional Regression Models - Three Case Study Area Data	188
6.3.2	Test to Determine Whether the 'Parallel' Regional Models Have Significantly Different Constants - Three Case Study Area Data	188
6.3.3	Results from the Regression Analysis of the Three Case Study Area Data with Regional Constants	190
6.3.4	Demographic Predictor Variables That May Account for the Different Regional Constants	194
6.3.5	Test for Regional Variances in Noise Levels (Student Data)	195
6.3.6	Results from the Test for 'Parallelism' of the Regional Models - Student Data	200
6.3.7	Test to Determine Whether the Parallel Regional Models are Concordant - Student Data	200
6.4	Testing of General Hypothesis 3 - Noise	204
6.4.1	Correlations Between Wind Corrected Noise Indices in the Two Noise Surveys	204
6.4.2	Correlations Between Calculated and Measured Noise Indices	208
6.4.3	Test to determine whether the relationship between the noise indices is a function of the area-type	214
6.5	Testing of Noise Hypothesis 1	221
6.6	Testing of Noise Hypothesis 2	232

7	The Statistical Testing of the Research Hypotheses Relating to Air Pollution	235
7.1	Introduction	235
7.2	Testing of General Hypothesis 1 - Air.	236
7.2.1	Tests Using Two-way Analysis of Variance	236
7.2.2	Identification of Pairs of Significantly Different Area-types	247
7.2.3	Tests Using Regression Analysis for the Two Dimensional Prediction Model	251
7.2.4	Results from the Regression Analyses	252
7.3	Testing of General Hypothesis 2 - Air	257
7.3.1	Residual from Land Use/Smoke Control Regression Analysis Plotted Against Region	257
7.3.2	Regression Analysis	258
7.3.3	Three-way Analysis of Variance Tests	266
7.3.4	Three-way Analysis of Variance - sub-set 1	266
7.3.5	Results from the Three-way Analysis of Variance Tests of Sub-set 1.	269
7.3.6	Conclusions	274
7.3.7	Three-way Analysis of Variance - Sub-set 2	274
7.4	Testing of General Hypothesis 3 - Air	278
7.4.1	Two-way Analysis of Variance	279
7.4.2	Regression Analysis	284
7.4.3	Testing for Regional Variations in the Ratio of Smoke to Sulphur Dioxide	285
7.4.4	Three-way Analysis of Variance	288
8	Summary and Conclusions of Research and Scope for Further Work	294
8.1	Summary of Principal Findings	294
8.2	Contribution to the Research Field	297
8.2.1	Noise Prediction	297
8.2.2	Air Pollution Prediction	298

8.2.3	General Research Field	299
8.3	Scope for Further Work	299
8.3.1	Scope for Continuation of the Proposed Research . . .	299
8.3.2	Further Calibration of the Pollution Prediction Models	300
8.3.3	Further Investigation of Demographic Variables as Pre- dictors	301
8.3.4	Prediction of Other Pollutants	303
8.3.5	Extending the Noise Pollution Model to Other Time Periods	304
8.3.6	Further Investigation of Regionality	305
8.3.7	Data Transformations	305
8.4	Recommendations for the National Pollution Data Base . . .	307
	References	
A	Technical Considerations on Noise	326
A.1	Details of the Student Generated Noise Data	326
A.1.1	Measurement Instructions	326
A.1.2	Reporting of Data by Students	326
A.1.3	Validation Checks on the Student Data	329
A.1.4	Sources of Error in the Student Data	329
A.1.5	Summary of Student Data	333
A.1.6	Noise levels (6pm. - 10pm.)	335
A.2	Comparison between the Three Case Study Area and the Stu- dent Noise Data	340
B	Technical considerations on demographic characteristics	344
B.1	Processing of the London Borough of Bexley land use data .	344
B.2	Derivation of Student Vehicle Density Variable	350
B.3	Types and Mix of Area-Type Characteristics within the sam- ple squares	352
B.3.1	Three Case-Study Area Data	352
B.4	Correlations between demographic variables	355
B.4.1	Correlations using data from all 3 case study areas . .	355

B.4.2	Regional differences in correlation coefficients	357
B.4.3	Student Land Use Data	360
C	Details of the national survey of smoke and sulphur dioxide	367
C.1	Selection of monitoring sites	367
C.2	Measurement Method	376
C.3	Accuracy of Sampling Method	377
C.4	Accuracy and Reproducibility of the Measurement Methods .	377
C.5	Errors Affecting Measurements of Smoke	378
C.6	Errors Affecting Measures of Sulphur Dioxide	378
C.7	Data Supplied on Magnetic Tape	380
C.8	Computation of Pollutant Parameters	383
C.8.1	Arithmetic Mean	383
C.8.2	Median	383
C.8.3	Percentiles	383
C.9	Summary Air Pollution Statistics	384

List of Figures

2.1	Distribution of average smoke levels at different types of site in London, Winter 1966-7 (WSL 72).	46
2.2	Distribution of average smoke levels at different types of site in London, Summer 1966 (WSL 72).	47
2.3	Distribution of average sulphur dioxide levels at different types of site in London, Winter 1966-7 (WSL 72).	48
2.4	Distribution of average sulphur dioxide levels at different types of site in London, Summer 1966 (WSL 72).	49
2.5	Distribution of annual average levels of grit and dust at different types of site in London, 1958-9 (WSL 72).	50
2.6	Distribution of average smoke levels at different types of site in Sheffield, Winter 1970-1 (WSL 72).	51
2.7	Distribution of average sulphur dioxide levels at different types of site in Sheffield, Winter 1970-1 (WSL 72).	51
3.1	The theoretical noise prediction matrix	76
3.2	Frequency of occurrence of the Pasquill stability categories over Great Britain.	81
3.3	Emissions of sulphur dioxide in thousand tonnes per year within 20 km. by 20 km. Ordnance Survey squares covering the U.K.	83
3.4	Theoretical air pollution prediction matrix	88
3.5	Daily traffic patterns in the U.K. February (DUN 69)	90
3.6	Daily traffic patterns in the U.K. August (DUN 69)	91

3.7	Regional divisions used in the analysis of the student noise data and the Warren Spring Laboratory air pollution data. .	94
4.1	Noise survey data sheet	122
5.1	Number and distribution of measurements during the noise survey period.	126
5.2	Spatial distribution of squares sampled in Milton Keynes . .	129
5.3	Spatial distribution of squares sampled in Bexley.	130
5.4	Spatial distribution of squares sampled in the West Midlands.	131
5.5	Frequency of measurements under different wind conditions .	132
5.6	Comparison of student data corrected and uncorrected for different wind conditions	135
5.7	Temporal variations in noise levels weekdays 10am. to 4pm. .	138
5.8	L_{A10} measurement distribution in sample square number 21 .	142
5.9	L_{A10} measurement distribution for the sample square with the largest difference between the mean and median values. .	143
6.1	Significantly different pairs of area-type classifications - noise survey data	170
6.2	Significantly different pairs of area-type classifications -student data	171
6.3	Two dimensional representation of 'parallel' regional models.	187
6.4	Studentised residuals for the full L_{Aeq} regression model plotted against region	197
6.5	Studentised residuals for the full L_{A10} regression model plotted against region	198
6.6	Studentised residuals for the full L_{A90} regression model plotted against region	199
6.7	Wind direction and studentised residuals for the L_{Aeq} regression model - Milton Keynes	223
6.8	Wind direction and studentised residuals for the L_{A10} regression model - Milton Keynes	224

6.9	Wind direction and studentised residuals for the L_{A90} regression model - Milton Keynes	225
6.10	Wind direction and studentised residuals for the L_{Aeq} regression model - Bexley	226
6.11	Wind direction and studentised residuals for the L_{A10} regression model - Bexley	227
6.12	Wind direction and studentised residuals for the L_{A90} regression model - Bexley	228
6.13	Wind direction and studentised residuals for the L_{Aeq} regression model - West Midlands	229
6.14	Wind direction and studentised residuals for the L_{A10} regression model - West Midlands	230
6.15	Wind direction and studentised residuals for the L_{A90} regression model - West Midlands	231
7.1	Normal and detrended normal plots for winter median of the daily values of sulphur dioxide - square root values	241
7.2	Normal and detrended normal plots for yearly mean of the daily values of sulphur dioxide - square root values	242
7.3	Normal and detrended normal plots for yearly median of the daily values of sulphur dioxide - square root values	243
7.4	Normal and detrended normal plots for yearly 98th percentile of the daily values of sulphur dioxide - square root values	244
7.5	Studentised residuals plotted against region - square root of sulphur dioxide winter median of daily values	259
7.6	Studentised residuals plotted against region - square root of sulphur dioxide yearly arithmetic mean of daily values	260
7.7	Studentised residuals plotted against region - square root of sulphur dioxide yearly median of daily values	261
7.8	Studentised residuals plotted against region - square root of sulphur dioxide yearly 98th percentile of daily values	262
7.9	Normal and detrended normal plots for the sulphur dioxide yearly median of daily values - un-transformed	270

7.10	Normal and detrended normal plots for the sulphur dioxide yearly median of daily values - square-root	271
7.11	The ratio of smoke to sulphur dioxide at United Kingdom monitoring sites	280
7.12	Normal and detrended normal plots for the ratio smoke to sulphur dioxide (winter median of daily values) - logarithmic transformation	283
7.13	Studentised residuals plotted against region - logarithmic transformation of the ratio smoke to sulphur dioxide	286
7.14	Subset 1 normal and detrended normal plots for the ratio smoke to sulphur dioxide (winter median of daily values) - logarithmic transformation	291
7.15	Subset 2 normal and detrended normal plots for the ratio smoke to sulphur dioxide (winter median of daily values) - logarithmic transformation	292
A.1	The BS 5969 sound level meter used by Open University students in their home experiments	327
A.2	Compulsory Noise Experiment instructions	328
A.3	Compulsory Noise Experiment results summary sheet (sheet 1)	330
A.4	Compulsory Noise Experiment results summary sheet (sheet 2)	331
A.5	Compulsory Noise Experiment results summary sheet (sheet 3)	332
A.6	The number of student measures of L_{Aeq} (6pm. to 10pm.) in each of the regions	341
A.7	The number of student measures of L_{A10} and L_{A90} (6pm. to 10pm.) in each of the regions	342
B.1	Format of 1971 Greater London land use survey data	345
B.2	Percentage of open space in each of sample squares.	352
B.3	Percentage of residential land use in each of the sample squares.	353
B.4	Percentage of commercial land use in each of the sample squares.	353
B.5	Percentage of industrial land use in each of the sample squares.	354
B.6	Vehicle densities in each of the sample squares	354

B.7	Frequency distribution of the percentage open space estimated by the students	361
B.8	Frequency distribution of the percentage residential land use estimated by the students	362
B.9	Frequency distribution of the percentage commercial land use estimated by the students	363
B.10	Frequency distribution of the percentage institutional land use estimated by the students	364
B.11	Frequency distribution of the percentage industrial land use estimated by the students	365
B.12	Combined frequency distribution of the student estimates of percentages of residential and institutional land uses	366
C.1	Concentrations of smoke - winter median of daily values . . .	368
C.2	Concentrations of smoke - yearly arithmetic mean of daily values	369
C.3	Concentrations of smoke - yearly median of daily values . . .	370
C.4	Concentrations of smoke - yearly 98th percentile of daily values	371
C.5	Concentrations of sulphur dioxide - winter median of daily values	372
C.6	Concentrations of sulphur dioxide - yearly arithmetic mean of daily values	373
C.7	Concentrations of sulphur dioxide - yearly median of daily values	374
C.8	Concentrations of sulphur dioxide - 98th percentile of daily values	375
C.9	Schematic arrangement of standard daily smoke and sulphur dioxide sampling apparatus (WSL 66).	376
C.10	British smoke calibration curve for 25mm. filter BS 1747 (BSI 69)	379
C.11	Correlation between smoke shade and mean lead concentrations in London (BAL 77)	380

Chapter 1

The Research Context

1.1 Introduction

At the heart of this thesis lies the problem of assessing the state of the environment on a national scale. The research that has been carried out represents an attempt to develop methods for tackling this problem and this thesis reports on a methodological approach to predicting ambient pollution concentrations in the United Kingdom using demographic characteristics.

1.2 Need for the Research

Within the past ten years or so, there has been an increasing demand for methods of describing or predicting environmental conditions at what might be termed the ‘strategic’ or ‘policy’ level. Spatially, this means at the urban, regional, national and even international scales.

A number of policy contexts have created this demand. The foremost of these are:

1. ‘State of the Environment’ Reports.

The precedent for these reports emerged in the United States of America during the 1970’s and was subsequently promulgated by bodies such as the World Health Organisation (WHO) and the Organisation for Economic Cooperation and Development (OECD). The United Kingdom produces a national digest of environmental pollution statistics

but this does not amount to the kind of spatially comprehensive report exemplified for instance by Eire's 'State of the Environment' Report 1985 (FOR 85).

2. The European Community.

Britain's entry into the European Economic Community (EEC) in 1973 brought an increasing internationalisation in United Kingdom pollution policy. Debate between the EEC member states about the relative severity of environmental problems has provoked a need for uniform and 'harmonised' approaches to environmental description. Although the original powers under the Treaty of Rome restricted the EEC to the 'removal of barriers to trade' a wide range of environmental regulations, such as environmental limits on smoke and sulphur dioxide concentrations, have been drawn up through these provisions. The recent introduction of the 'Single European Act' (1987) has amended the Treaty of Rome to include, *inter alia*, explicit powers for environmental pollution control.

3. Development Planning.

The widening of assisted area status in the United Kingdom during the mid-1980's, coupled with new town development (e.g. Milton Keynes) and urban regeneration policies aimed at revitalising the inner city areas, have created needs to examine intra and inter regional variations in environmental conditions as part of the planning process. Knowledge of the prevailing environmental conditions within an area assists in the decision making process for the appropriation of funds for environmental improvement schemes and in the identification of suitable sites for a particular development. The 'hi-tech' industries, for instance, have very stringent environmental requirements.

The Department of the Environment's circular 'Planning and Noise' (10/73) (DOE 73) contains advice to Local Authorities on the criteria for assessing whether a noise-sensitive or noisy development would be suitably located in a particular area. The circular's aim is to promote

positive planning to reduce the risk of intrusion of noisy developments and to meet existing problems. It is recommended that the ambient environmental noise levels¹ within a proposed development area should be ascertained before considering an application for a new development. The recommended method for calculating the background² environmental noise levels is that given in the British Standard BS 4142 (1967) which is discussed further on Page 15. This method is considered to over estimate and, therefore, may be unreliable as evidence in the consideration of a new development proposal. The 1981 version of BS 4142 standard recommends measurement wherever possible rather than the use of the calculation procedure (see also page 24). The DOE circular (10/73) is currently under review. It is uncertain what the consequences will be for future development planning if the circular is updated.

4. Environmental Impact Appraisal.

The recent EEC directive on environmental impact appraisal of large-scale development projects (EEC/85/337) has created an explicit need for large-scale 'baseline' data on current environmental conditions. In assessing the environmental impact of a new development, it is necessary also to consider the existing background or baseline environmental conditions in order to assess fully the changes in conditions likely to be created by a new development such as a power station, airport, open cast mine, exhibition centre etc.

In many cases it is possible to derive baseline data from environmental monitoring programs but this is often the most time consuming and costly aspect of an environmental impact assessment, especially if monitoring equipment needs to be purchased or the monitoring programme is to be undertaken at some distance from the surveillance

¹Totally encompassing sound in a given situation at a given time usually being composed of sound from many sources near and far.

²Denoted by the A-weighted sound pressure level obtained by using the time-weighting 'slow' that is exceeded for 90% of the time interval considered e.g. symbol $L_{A90,1hr}$.

team's base. A much more cost effective approach would be to use predictive techniques to establish the ambient environmental conditions.

Methods are currently available for local and even urban scale environmental prediction but are not yet extended to the regional or national scale. The demand for information at the scales identified previously, cannot yet be met by existing methods. This research therefore seeks to identify and test possible methods for meeting this need for regional/national environmental information.

1.3 Considerations of Measurement and Prediction Techniques

Both measurement and prediction techniques are widely used to assess environmental quality. Measurement techniques are used mainly where specific sources, sites or recipients are of interest, however, they become impractical where a large number of measurements are required or where assessment is required of previous or future conditions. Measurement techniques are very often impractical for the assessment of environmental conditions on a national scale. Prediction techniques are widely used in the fields of air, water and noise pollution assessment.

Many of the prediction techniques are source specific, e.g. pollutants from road vehicles (DOE 75, HIC 82, WAT 82 and DOT 83). These techniques use detailed source information such as, in the examples above, vehicle flow, vehicle speed, distance from zero base line, etc.

Many of these source specific predictive models can only be used to assess a very small number of sources either because of their complexity and the unwieldy nature of the large data input required, or because the models become significantly inaccurate on a larger scale.

Other source based predictive models can handle larger numbers of pollutant sources by reducing the number of predictor variables required for each source, with a resulting loss in accuracy.

Ambient environmental conditions within an area cannot be predicted from a combination of these source specific predictive models as they do not form a comprehensive set.

An alternative approach is area-based prediction. This method uses the demographic characteristics of an area to predict the ambient environmental conditions.

In theory, area-based methods should provide a convenient and cost effective method for predicting ambient environmental conditions if calibrated with demographic data that are readily available and spatially comprehensive. Area-based prediction techniques should be most useful where the alternative of comprehensive measurement would be prohibitively expensive or where prediction either of future or of previous environmental conditions are required.

1.4 The Potential of Area-based Methods of Prediction

Previous researchers have used two approaches in developing area-based predictive models. The approach most favoured in the prediction of air pollutants is to estimate the pollutant emissions at source. The estimated emissions can then be combined with a dispersion model (MYR 76, ROB 77 and POC 79) or compared with measured ambient pollution levels to produce a predictive model.

The second approach uses statistical correlations between demographic data and measured pollution. This method is favoured in the prediction of ambient noise pollution, largely due to the multiplicity of noise sources often found within an area (ATT 76a, ATT 76b, POC 79 and POC 83) and has been used by Wood *et al.* in the prediction of air pollution (WOO 74). Pocock's model for predicting air pollutants (POC 79) is analogous to the Gifford 'box model' for air pollution (without dispersion) (GIF 73).

In theory, area-based methods should provide the most practical method for predicting environmental conditions on a national scale. However, the

spatial aspect of this technique (i.e. the required spatial resolution of the demographic data) renders it impractical for predicting some pollutants that have restricted dispersion.

Land contamination is localised and can therefore be predicted using a small spatial scale. Noise pollution, however, can be significant at greater distances as shown in Section 3.2.1 and therefore requires a larger spatial scale of prediction than land pollution. The propagation of air pollution is still more complex.

Thermal air pollution and noise pollution are both forms of energy and both forms are readily dissipated through the atmosphere. Their effects are usually fairly local and can therefore be predicted using a smaller spatial scale than the other forms of air pollution. Other forms of air pollution are chemical and their chemical characteristics have a significant effect on the application of area-based methods for these pollutants. For instance, where ozone is formed from the chemical breakdown of nitrogen dioxide in the presence of ultraviolet light from solar radiation it will not always be located close to the source of the nitrogen dioxide, and the solubility of the sulphur dioxide molecule in water can result in 'acid rain' at great distances from the pollutant's source.

The air and noise pollution emissions themselves may exhibit diurnal, weekly or annual cycles according to man's needs and/or working patterns as well as the more unpredictable variations due to different weather conditions (PAR 68 and MEE 56).

Weather conditions can assist in the removal of air pollutant chemicals from the atmosphere or their conversion into other pollutants. Weather conditions can also assist in the dispersion of air pollutants and the propagation of noise. Wind direction is important in determining the direction of the dispersal in the case of air pollution or propagation range in the case of noise.

River water pollution has a restricted dispersion path. The pollutants are carried down stream of the source and remain within the confines of the river banks. The concentration of pollutants at any point in the river is

dependent upon the number and strength of pollutant sources upstream and the rivers ability to recover from the particular forms of pollution, either by dilution, biodegradation or sediment adsorption.

Unlike air and noise pollution, water pollution can be 'exported' or 'imported' from one area to another. Water pollutants may be directed away from their area of production (e.g. along sewage pipes). Where this occurs the river quality within the area of pollutant production may be of higher quality than the local demography suggests. The river receiving the 'exported' pollutants will have a lower quality than its surrounding demography suggests.

The efficiency of water treatment plants and the frequency and severity of unsatisfactory storm overflows are also major factors affecting water quality within an area.

We can conclude:

1. that there is no basic causal relationship between the demography of an area and an area's water quality and
2. that sources of pollution outside the area of prediction can determine the levels of pollution within the area of prediction.

In this regard, therefore, area-based methods of prediction are unsuitable for predicting water quality.

This is confirmed by the results of Wood *et al.*'s spatial study (WOO 74) of water quality in the Greater Manchester area. They found that there was a relationship between the river quality in each local authority area and the following two predictors:

1. the average quality of rivers flowing into the local authority (representing an 'external' characteristic), and
2. the biological oxygen demand (BOD) load per day per mile discharged into the river within the local authority area (representing an internal characteristic).

Of the two predictors the external characteristic is the better predictor of river quality.

Land pollution can be defined as 'any physical or chemical alteration to land which causes its use to change and to render it incapable of beneficial use without treatment'.

Land pollution falls into three broad categories:

1. Misuse of land, e.g. eyesores, litter.
2. Disuse of land, e.g. derelict buildings.
3. Chemical contamination of land, e.g. cyanide waste, refuse, pesticides, etc.

Misuse and disuse of land often results in a deterioration in an area's appearance.

The aesthetic appearance of a neighbourhood is an area-based concept. Although the nature of eyesores and their location cannot be predicted from demographic variables, it is possible that some areas with certain demographic characteristics will have an appearance that is generally poorer than others.

This hypothesis has been tested by a number of previous researchers (BUC 71 and POC 79).

Chemical contamination of land can, in some cases, be related to the type of land use within an area in the past and at present e.g. the toxic effects of spoil from Roman lead and silver mines are still apparent in parts of North Wales and cyanide waste from old coal gasification plants can often be found close to modern gas works which no longer produce the wastes.

Since the 1972 'Deposit of Poisonous Waste Act' much of the noxious wastes arising from human activities are not disposed of in the areas where they originate. Most wastes, with the exception of agricultural wastes and litter, are transported away from the area of origin.

Where this occurs there will not be a causal relationship between the demographic characteristics of the producer area and the type of contaminated

land therein. However, it may be possible to relate land use in the receiver area to the degree of contaminated land by considering the historical land use and present day waste disposal practices and by classifying an area by the types of wastes it has received.

The limited dispersion of land contaminants requires a small scale of prediction to identify areas of contaminated land and very detailed demographic data for both present day and historical land usage.

Although there are a number of factors affecting the dispersion characteristics of land, noise, and air pollutants, it can be seen that with due consideration of these factors and with the selection of an appropriate spatial scale for prediction, these pollutants can, in theory, be predicted using area-based methods.

1.5 Basic Hypothesis for Area-based Studies

Fundamental to the area-based prediction of outdoor environmental pollution is the hypothesis:

‘That average pollution levels within the area of prediction are not affected significantly by pollution from sources outside of the area of prediction.’

To develop a successful area-based model to predict a pollutant, a spatial scale for prediction must be selected so that this hypothesis is true. This spatial scale differs between pollutant and pollutant media and is a function of the pollutant’s ability to spread away from its source.

It is necessary to select a few environmental pollutants and/or media which can be used to test the hypothesis. The selection of these pollutants/media is subject to several constraints. The most important theoretical constraint is that the pollutants need to be spatially comprehensive. Clearly river pollutants do not meet this requirement as their dispersion is limited by the banks of the river and by the direction of water flow. Therefore, river pollutants are excluded from further investigation. The main research demands and constraints are identified in Section 1.7.

1.6 Aims and Objectives of the Research

Since the detailed data requirements for the development of a prediction model for land contamination are outside the scope of this research, this thesis describes the exploration of area-based methods for predicting noise and air pollutants on a national scale.

It is intended that the resulting prediction models will provide a practical and cost effective basis for the description of the overall environmental quality within the United Kingdom.

The research objectives are to:

1. Test the hypothetical relationship between selected pollutants and demographic variables.
2. Identify key predictor variables.
3. Develop operational models for predicting the selected pollutants.
4. Calibrate the predictive models.

1.7 Research Demands and Constraints

The research design is influenced by theoretical and operational requirements.

The theoretical requirements are that:

1. The indicators selected must represent the pollutant.
2. There must be either a direct or indirect causal relationship between environmental conditions and the predictor.
3. The research should be consistent i.e. the principals and hypotheses underlying model development should be uniformly applied to all pollutants and pollutant media studied.
4. The research propositions should be testable.

The following operational criteria must also be fulfilled:

- The model should predict values of pollution accurately and representatively. Any increase in error due to using a prediction method instead of a measurement method should be outweighed by the difference in costs.
- The model should discriminate between different neighbourhood pollution climates.
- The prediction model should be versatile and should be applicable to all area types at an appropriate scale.
- The model should be easy to apply using data that are readily available.
- Its application should be unambiguous.

This research seeks to develop new area-based predictive models for predicting certain environmental conditions that represent improvements over previous area-based methods either in accuracy or in generality. The models are developed within the theoretical demands and constraints and to meet the operational criteria better than previous models.

1.8 Structure of the Thesis

The research strategy involves the following steps:

- Selection of pollutants.
- Selection of pollutant indicators.
- Construction of the theoretical prediction models.
- Calibration of the prediction models.
- Hypothesis testing.
- Development of models.

The following Chapters are based on this sequence. Chapter 2 reports on previous work in this field. The theoretical models are developed in Chapter 3. The field work method is developed and described in Chapter 4. The noise data are summarised in Chapter 5. Chapters 6 and 7 contain the analysis of the calibration data and reports on the calibration of the predictor model for air and noise data respectively. Chapter 8 reports the research findings and outlines the opportunities for further work.

Chapter 2

Literature Review

2.1 Introduction

For the purposes of predicting air and noise pollution the types of pollutant emissions may be classified as either:

- point source emissions,
- line source emissions or
- area source emissions.

Point source emissions are emissions from a specific single source, line source emissions refer to emissions that can be approximated to an infinite continuous linear source and area source emissions are the combined emissions of a large number of pollutant sources in a well defined area each producing relatively small quantities of the pollutant.

The dispersion of point source emission of air pollutants are most commonly modelled using Gaussian plume models such as those presented by Turner (TUR 70) and Montgomery *et al.* (MON 76). These models allow for diffusion within the atmosphere. Puff models (MUR 78) are also used to model point source emissions of air pollutants but over shorter time periods than the Gaussian Plume models. Numerous line source prediction models have been developed by adapting the Gaussian plume model used for point sources. Linear source prediction models are most often used to model air

pollution from roads. Examples of linear source prediction models are given in Turner's 'Workbook of Atmospheric Dispersion Estimates' (TUR 70). In predicting traffic noise, roads are often modelled as line sources, whereas individual vehicles may be regarded as point sources.

Both point and line source prediction models are source specific and have often been developed for the assessment of the environmental impact of a particular activity or development such as a new road (DOE 75 and HIC 82). The source specific models for noise and air pollution are based on the laws of propagation in the case of noise and atmospheric dispersion in the case of air pollutants. As a result the point and line source models often require detailed information on source strengths, meteorological conditions, screening etc. Where a large number of pollutant sources are to be considered these prediction methods are prohibitively complex to apply and would, therefore, be impractical for predicting noise and air pollution on a national scale. In addition to these practical considerations, the models that are currently available do not form a comprehensive set. Area-based prediction techniques offer the most practical alternative as they do not require such detailed information.

The following section of this chapter present a detailed review of area-based methods of prediction. The area-type classifications used to present United Kingdom noise and air pollution data are also reviewed, as the degree to which these differentiate between values of either air pollution or noise is indicative of the basic characteristics that, potentially, would be predictor variables in a national area-based prediction model.

2.2 Evaluation of Area-based Methods of Noise Prediction

A few researchers have used the causal relationship between demographic variables and noise levels to derive models for predicting ambient environmental noise pollution (ROS 53, BSI 67, ISO 71, ATT 76a, PRA 78, POC 79, POC 83 and KUN 84). These models predict a variety of different noise in-

dices. Models have been derived that predict the background noise level L_{A95} (ISO 71) or L_{A90} (BSI 67, ATT 76a and POC 79), the mean noise level L_{A50} (PRA 78), the median noise level (KUN 84), the peak noise level L_{A10} (POC 79 and POC 83) and a calculated equivalent continuous noise energy level $L_{Aeq,5min}$ (POC 79 and POC 83).

The accuracy of each of these models are determined partly by the type of noise index they predict.

The background noise level is best suited to area-based predictions as it is less likely to be affected by intermittent local noise sources that may be unrepresentative of the area. Both the mean and median noise levels will be more sensitive to local sources than the background level whilst the average peak and L_{Aeq} values will be most affected.

The original version of BS 4142 (BSI 67) did not define background level as L_{A90} but as mean minimum level. More typically this may be L_{A95} or L_{A99} . L_{A99} may well represent the occasional minimum. Both L_{A95} and L_{A99} will be more dependent on area-type than L_{A90} . The International Standard Organisation recommendation ISO/R 1996: 1971 defined the background noise level as L_{A95} .

2.2.1 Area-type Classifications

Each of the previous area-based models predicting noise pollution (ROS 53, BSI 67, ATT 76a, PRA 78, POC 79, POC 83 and KUN 84) include land use as the basic predictor, each area being classified according to the type and mix of land use found within it.

BS 4142 and Attenborough *et al.* used the following land use categories:

1. rural (residential)
2. suburban, little road traffic
3. urban (residential)
4. predominantly residential urban but within some light industry or main roads

Table 2.1 Comparison of land use categories used in three previous noise models land use categories

Prabu <i>et al.</i> (PRA 78)	Pocock (POC 79)	Kuno <i>et al.</i> (KUN 84)
Residential	Residential	Residential
Institutional	Industrial	Industrial
Industrial	Commercial	Quasi-industrial
Commercial	Open Space	Commercial
Commercial-Public	Residential/Industrial	Neighbourhood Commercial
	Residential/Commercial	Unclassified
	Commercial/Industrial	
	Residential/Open Space	
	Industrial/Open Space	

5. general industrial area intermediate

6. predominantly industrial area with few dwellings.

ISO/R 1996 (ISO 71) uses similar land use categories:

1. rural residential, zones of hospital, recreation,
2. suburban residential, little road traffic,
3. urban residential,
4. urban residential with some workshops or with business or with main roads,
5. city (business, trade, administration),
6. predominantly industrial area (heavy industry),

and is in fact derived from the BS 4142 prediction model.

More comprehensive land use categories were used by Prabu *et al.*, Pocock and Kuno *et al.* as shown in Table 2.1.

Table 2.2 'Intensity of land use' categories used in previous noise models

Model	Prabu <i>et al.</i>	Pocock	Kuno <i>et al.</i>
Variable	Population density	Road Network density	Population density
Categories	High Medium Low	Dense Medium Sparse	Residential Exclusively Residential 1 Exclusively Residential 2

Many of the models have used other predictor variables to help improve the poor differentiation between noise climates provided by land use alone.

Three of the models (PRA 78, POC 79 and KUN 84) used an additional predictor variable that indicates the degree of noise producing activity in an area.

Both Prabu *et al.* and Kuno *et al.* used population density as a predictor. However Kuno *et al.* only used population density to distinguish between three types of residential area.

Population density is an indirect measure of the degree of noise producing activity. A comprehensive source of population density is the census, which provides figures for the population density at midnight. This information can be used to differentiate between residential housing densities. However, it cannot be used to differentiate between degrees of commercial or industrial land use as the majority of the population will be away from these areas at midnight.

Pocock used road network density to indicate the degree of noise producing activity within an area. This predictor variable, unlike night-time population density, can be used across all categories of land use. Pocock's network density variable is calculated by assigning a score to each type of road junction; T-junctions score 1, crossroads score 2, etc. The totals of these scores within a 1 km² square gives the network density. This method does not take account of through roads such as motorways.

The categories of predictor variables indicating the intensity of land use used in each of these models are given in Table 2.2.

Table 2.3 Regional correction factors applied to Attenborough *et al.*'s model

Region	Correction in dB(A)
S E England	0
Scotland	-2.16
N England	-1.64
W England	-1.76
E Anglia and Midlands	-1.88

Prabu *et al.* and Kuno *et al.* both used an additional predictor variable which places a more direct emphasis on the contribution to ambient environmental noise made by traffic.

Prabu *et al.* applied corrections for the type of service road within each area (local, distributor, or major road). Kuno *et al.* classified each area according to the traffic volume (very high, high, not so high and low) and the number of lanes of the adjacent road (4 or more, 2 and 3, and 1).

None of the variables above take into account the temporal variations in noise levels. However, Pocock's models (POC 79 and POC 83) are calibrated for the period 10 am. to 4 pm.: a period of the day where noise levels remain fairly constant (GLC 65). Prabu *et al.* (PRA 78) model predicts for the time period 8 am. to 8 pm. BS 4142: 1967 and Attenborough *et al.* (ATT 76a and ATT 76b) used corrections for the time of day.

In Attenborough *et al.*'s model using 1974 data (ATT 76b), a correction factor is also applied for regional variation in noise levels (see Table 2.3).

Attenborough *et al.* also added corrections for the type of major noise source (ATT 76a and ATT 76b) and the distance to major noise source (ATT 76b) combining both area characteristics with source characteristics in the predictive model.

Pocock's later model (POC 83) is a modified version of his 1979 model (POC 79). This model uses twenty distinctive types of urban area found within the West Midlands area, shown in Table 2.4, as the predictor variables. These area classifications free the spatial classifications in the noise

prediction model from the artificial simplicity of the earlier, two variable, prediction model.

Pocock added a wind correction factor to all noise measurements to normalise all data to light wind conditions (i.e. less than Beaufort 3). The wind correction factor is discussed further in Section 5.2.1.

2.2.2 Prediction Model Structures

Where more than one predictor has been used in a model the indicators are combined using one of two forms of model structure:

1. linear additive form or
2. matrix form.

The linear additive form (ROS 53, BSI 67, ISO 71, ATT 76a, ATT 76b, KUN 84 and PRA 78) assigns positive or negative values to each category of the variables and these are then added to a basic noise level. The matrix form (POC 79 and POC 83) uses the area descriptor variables (e.g. land use, road network density) as ‘axes’ of the matrix. Each ‘cell’ within the matrix defines a unique area classification to which typical levels of ambient neighbourhood noise are assigned.

Of the two forms, the matrix form is the more appropriate as a basis for a general model as it allows for interdependence between the spatial predictor variables whereas the linear additive form does not take this into account. The area-type defined within each of the matrix ‘cells’ can be identified with a quantified description which will reduce errors due to misclassification of areas.

Attenborough *et al.* (ATT 76a) and Prabu *et al.* (PRA 78) both used linear additive models without interaction variables that have the general formula given in Equation 2.1.

$$LdB(A) = B_o + B_1.X_1 + ... + B_N.X_N \quad (2.1)$$

Table 2.4 Characteristics of the twenty area-types in the Pocock's revised model (POC 83)

Road Network Density				
A (High)	B	C	D	E (Low)
Majority commercial small amount of industry and residential land.	Majority residential, small proportions of industry and recreational land.	Almost all residential a very small amount of vacant or recreational land or small shopping areas.	Mainly industrial but also vacant land and residential.	Industrial vacant and recreational land, broadly mixed.
Majority residential but with a considerable mix	Broadly even mix of residential and industrial land.	Broad mixed industry and residential land.	Even mix of residential and recreational land.	Majority recreational but mixed with substantial residential areas.
Majority residential, small proportions less than (20%) of recreational or vacant land.	Majority residential but also small commercial areas.	Majority residential, some vacant land possibly associated with industry.	Mostly residential but substantial presence of vacant land, also some industry.	Majority agricultural but noticeable amount of residential land.
	Majority residential but also noticeable amounts of recreational and/or some vacant land.	Majority residential but significant amounts of recreational and/or some agricultural	Agricultural/residential mix, with agricultural predominant.	Majority usually agricultural land but also mixed with substantial recreational land.
				Almost entirely agricultural.

where:

$L_{dB(A)}$ is the predicted noise level,
 B_0 is the equation constant,
 $B_1 - B_N$ are the coefficients of the predictor variables
computed by multiple regression for best least
squares fit and
 $X_1 - X_N$ represent the predictor variables

The predictor variables ($X_1 - X_N$) used in both models are binary dummy variable and correspond to the area-type classifications. The predictor variables take value 1 or 0 according to the characteristics of the area. If a characteristic is absent the value is 0, if it is present the value is 1.

The linear additive and matrix model structures both have the same method for applying correction factors. The correction factor categories are assigned different values, either added to or subtracted from the predicted value.

2.2.3 Calibration of the Predictive Models

Stevens, Rosenblith and Bolt, BS 4142 and ISO/R 1996: 1971

Annex XV of the Wilson Committee report (WIL 63) states that their method for predicting noise is based upon work by Stevens, Rosenblith and Bolt (STE 55) and by Kosten and Van Os (KOS 62). These methods provide the basis for the subsequent BS4142: 1967 or ISO/R 1996: 1971 prediction models. It is not clear whether the model has been derived subjectively or objectively. However, the prediction method and structure of both of these methods are very similar to the model proposed by Stevens *et al.* (STE 55) for relating aircraft noise to probable community reaction. All three models have the same types of correction factors which are made in 5 dB intervals.

The Stevens *et al.* model uses 5 dB interval corrections. It was considered difficult to derive correction factors with any greater degree of accuracy since many of the initial relationships were based on the intuition of the authors (ELD 75).

The similarities between these models suggests that the BS 4142: 1967 and subsequently ISO/R 1996: 1971 models were derived in a similar fashion.

Attenborough, Clark and Utley

Attenborough *et al.*'s models are derived from outdoor background noise measurements taken by adult home-based Open University students studying the foundation course T100: 'The Man-made World'.

1353 measurements of background noise levels were used to calibrate the 1972 data model (ATT 76a) and 1300 measurements were used to calibrate the 1974 data model (ATT 76b).

The students visually assessed the mean minimum needle fluctuation on the display of a 'sound level indicator' for a period of 2-5 minutes. The sound level indicator did not meet the British Standard requirements for industrial grade sound level meters BS 3489 (BSI 62). It was, however, of the highest standard attainable within a limited (educational) budget. It was calculated that the total expected standard error contribution due to the indicator's performance errors for a typical traffic noise spectrum would only be +1 dB(A). Nevertheless the average 'correction' applied for instrument error in the background noise level predictions was -3 dB(A). A recent comparison with T234¹ data suggests that the indicators frequency response and lack of windshield resulted in overestimates of up to 10 dB(A) in background noise levels.

The students reported the results of their noise measurements and details on the area-type, Ordnance Survey grid location, major noise sources, time of day, etc., either through simple report forms or through the universities regional computer centre network. The area-type data were derived by subjective assessment of an undefined area around the measurement site.

¹T234 is an Open University course entitled 'Environmental Control and Public Health'.

Prabu and Chakraborty (PRA 78)

Prabu and Chakraborty carried out a noise survey of the city of Calcutta (area 104 km²). Measurement sites were selected at nodal points of a 500 m grid across the whole of the city area. Fifty spot readings of L_{A50} were taken at 5-second intervals at each of the measurement sites. Measurements were taken using a standard sound level meter during the period March to May 1977.

Data for categorising the measurement sites were derived from planning records kept by the Calcutta Metropolitan Planning Organisation and night-time Population Census data.

Pocock

Pocock's model was calibrated and validated using noise survey data gathered from the West Midlands region.

Each 1.25 km² square within the West Midlands was classified according to its characteristics in to one of the area-type categories. A sample of these 1.25 km² squares was selected and surveyed in a three phase noise survey spaced over six months.

In phase 1, each of the eighteen area-types in the model were calibrated using one 1.25 km² square for each of the area categories.

In phase 2, different 1.25 km² squares were used to further calibrate eight of the area-type classification and three more (1.25 km²) squares were used to calibrate three of the area-types a third time.

Thus a maximum of only three (1.25 km²) squares were used to calibrate each of the area-type classifications. Phase 3 in the noise survey re-surveyed seven of the (1.25 km²) squares surveyed in phases 1 and 2.

Twenty positions in each of the (1.25 km²) squares were selected using a stratified random cluster sampling technique. Each site was sampled during two 5-minute periods separated by a ten minute interval.

Data for categorising each of the 1.25 km² by land use were taken from a land use base map provided by the West Midland County Council. The

road network density was calculated from 1:50,000 scale Ordnance Survey maps of the West Midlands region.

Kuno, Zang, Ikegaka and Mishina (KUN 84)

Kuno *et al.* used 315 measurements of 10 minute L_{Aeq} monitored continuously over 24 hours at residences in Nagoya city, Japan to calibrate their model. Measurements were taken from the porch or garden of each residence using an L_{Aeq} meter (type VR 4202B).

2.2.4 Model Performance

The accuracy of the BS 4142 model has been widely discussed and is generally thought to overestimate the background noise levels in the area that it describes.

Table 2.5 compares the levels of background noise found by subsequent researchers, in the BS 4142 area-type categories, with the values defined in BS 4142. The Gilford and Norris data are from a noise survey of the West Midlands (GIL 73) which is reviewed in greater detail in Section 2.3.

The International Standards Organisation recommendation ISO/R 1996: 1971 uses a basic noise level of 35 to 45 dB(A). If the land use correction factors are added to this value then the model predicts the L_{A95} noise levels in Table 2.6.

It is interesting to note that the ISO/R 1996: 1971 has now been cancelled and replaced by the current ISO standards:

- ISO 1996-1 (1982)
- ISO 1996-2 (1987) and
- ISO 1996-3 (1987)

and that these new standards do not include the L_{A95} prediction method. Also the notional background model no longer appears in the latest version of BS 4142 (1988).

Table 2.5 Comparison of the national noise levels (L_{A90}) in BS 4142 categories with results from three U.K. studies

BS 4142 Category	BS 4142	Attenborough <i>et al.</i> *	Gilford and Norris	Pocock
Rural (Residential)	50	44.4	43	44.8
Suburban (little road traffic)	55	46.7	42	47.5
Urban (Residential)	60	52.0	47	52.2
Residential (some industry)	65	54.1	50	56.1
Intermediate, Industrial and residential)	70	56.6	57	57.7
Predominantly industrial	75	57.0	52	57.4

*Includes addition of 0.3 dB(A) to give 'working day' mean.

Table 2.6 Predicted L_{A95} noise levels from ISO/R 1996: 1971.

Land use category	L_{A95}
Rural residential, zones of hospitals, recreation.	35 - 45
Suburban residential, road traffic.	40 - 50
Urban residential.	45 - 55
Urban residential with some workshops or with business or with main roads.	50 - 60
City (business, trade, administration).	55 - 65
Predominantly industrial area (heavy industry).	60 - 70

Table 2.7 Comparison of noise model performances

	Models			
	Attenborough <i>et al.</i>	Prabu	Pocock	
Predicted value	L _{A90}	L _{A50}	L _{A90}	L _{A10}
No of predictor variables	15	11	2	2
Standard error of estimate	10.2	4.294	1.6	1.8
Multiple correlation coefficient	0.573	0.841		
% of variance explained	32.8	70.7		
Overall F ratio	43.5			
Adjusted standard error of estimate*	10.3			
Adjusted multiple correlation coefficient*	0.566			

*Adjusted for the degrees of freedom

In comparing the models it is important to note that Attenborough *et al.* offer a national (U.K.) model whereas Prabu's model applies only to Calcutta and Pocock's to the West Midlands. Also Pocock's model predicts an area average noise level whilst the other models predict single point noise levels.

Table 2.7 compares the model performance of three area-based noise prediction models.

2.3 Evaluation of Area-type Classifications Used to Present Noise Pollution Data

The causal relationship between area-type and ambient environmental noise levels has often been indicated in the noise surveillance strategy used by researchers (MOC 67, PAR 68, GLA 79, MAN 76, CON 78, FID 78, GLA 79, BRO 81 and KUN 84) and in the way that these noise surveillance

data are presented. This section reviews the area-type classifications that have been used to present large scale United Kingdom noise survey data. The aim of this section is to identify those classifications that successfully discriminate between different measures of noise pollution.

2.3.1 The London Noise Survey.

The London noise survey 1961 to 1962 measured ambient noise levels across a thirty-six square mile area of central London. The purpose of the study was to determine the areas of London most likely to be affected by helicopter noise. The London based survey was preceded by a pilot noise survey at twenty locations in Watford.

Twenty-four consecutive hourly two minute recordings of noise were taken at a total of 540 locations positioned 500 metres apart and arranged in a grid configuration. Details of the measurement position, weather conditions, and the local area's demographic characteristics were noted for each of the measurement sites.

Preliminary results from the survey were reported by the Wilson Committee (WIL 63) and by Parkin *et al.* (PAR 68). The final results were reported by the Greater London Council (GLC) (GLC 65). Both the Wilson Committee and Parkin *et al.* reported that at 84% of the sites monitored road traffic noise predominated. The monitoring sites were classified according to their proximity to different types of road, land use and time of day. Tables 2.8, 2.9 and 2.10 show the final results from the survey published by the GLC.

Table 2.8 Results from the London noise survey

Road class & and microphone position	Time period												Number of measurement sites
	7am. - 10am. 4pm - 7pm			10am. - 4pm.			7pm. - 12pm.			12pm - 7am			
	L _{A50}	L _{A90}	L _{A10}	L _{A50}	L _{A90}	L _{A10}	L _{A50}	L _{A90}	L _{A10}	L _{A50}	L _{A90}	L _{A10}	
A	71.0	76.5	66.0	70.5	76.0	65.5	65.0	72.0	61.0	57.5	67.5	51.5	41
AX	64.0	68.5	59.5	63.5	68.5	59.5	59.0	65.0	54.5	52.0	59.0	48.0	39
B	64.5	72.5	60.0	64.0	71.5	58.5	58.5	67.0	53.5	49.0	57.0	46.0	23
BX	61.5	68.0	57.5	61.5	67.5	58.0	55.0	62.0	51.0	46.5	53.5	43.5	11
C	62.0	68.0	57.5	63.0	69.0	58.5	55.0	62.0	51.0	47.0	53.5	44.0	15
CX	62.0	67.5	58.5	62.0	68.0	58.0	55.5	60.0	52.0	47.0	51.0	44.5	11
D	57.5	63.5	54.5	57.0	62.5	53.5	52.5	57.5	49.0	45.5	50.5	43.0	118
DX	57.5	63.0	54.5	58.0	62.0	55.0	51.0	57.0	49.0	47.0	51.0	44.5	61
D/A	62.5	68.0	58.5	62.5	67.5	58.5	58.5	64.5	54.5	51.5	58.0	47.5	54
D/AX	60.0	66.0	56.5	60.0	65.0	57.0	55.0	60.5	51.5	49.0	54.0	46.5	13
D/B	60.0	66.0	56.5	60.0	65.5	56.0	55.0	60.5	51.0	49.0	52.5	46.0	23
D/C	59.5	65.5	55.5	57.5	64.0	54.0	53.5	59.0	50.5	48.0	52.0	45.5	17
E	54.0	58.5	52.0	55.0	58.0	53.0	50.5	54.0	48.5	47.5	50.0	45.5	18
E/A	59.5	63.0	57.5	60.0	63.0	54.5	55.0	59.0	53.0	51.0	55.0	49.0	36
E/B & E/C	57.5	61.5	55.0	57.0	61.0	54.0	51.5	54.5	50.0	47.5	50.5	45.5	13
E/D	56.5	61.0	53.5	56.5	60.0	53.5	51.5	55.0	49.0	47.5	50.5	45.0	13
AXX & BXX	55.5	60.0	53.0	56.0	60.5	53.0	51.5	55.5	48.5	47.0	51.0	45.0	12
CXX & DXX	55.5	60.0	52.5	56.5	60.5	54.0	50.5	54.5	47.5	46.0	49.5	43.0	22

A = A road, predominantly through traffic, B = B road, through traffic, local traffic and bus routes,
C = C road, predominantly local traffic with some bus routes, D = D road, local traffic, no buses,
E = Open space, X = Off road, but not shielded from it, XX = Off road, shielded from noise from the road,
D/A = In D road, but affected by noise from A road, D/B = In D road, but affected by noise from B road,
D/C = In D road, but affected by noise from C road, E/A = On open ground, but affected by noise from A road,
E/B = On open ground, but affected by noise from B road, E/C = On open ground, but affected by noise from C

Table 2.9 Results from the London noise survey - continued.

Road class & and microphone position	Time period												Number of measurement sites
	7am - 10am 4pm - 7pm			10am - 4pm			7pm - 12pm			12pm - 7am			
	L _{A50}	L _{A90}	L _{A10}	L _{A50}	L _{A90}	L _{A10}	L _{A50}	L _{A90}	L _{A10}	L _{A50}	L _{A90}	L _{A10}	
A combined	67.5	72.5	63.0	67.0	72.0	62.5	62.0	68.5	58.0	55.0	63.0	50.0	80
B combined	63.5	71.0	59.0	63.0	70.0	58.5	57.5	65.5	52.5	48.0	55.5	45.0	34
C combined	62.0	68.0	58.0	62.5	68.5	58.0	55.0	61.0	51.5	47.0	52.5	44.0	26
D combined	58.5	64.5	55.0	58.5	64.0	55.0	53.5	59.0	50.0	47.5	52.5	45.0	286
E combined	57.5	61.5	55.0	58.0	61.0	54.0	53.0	56.5	51.0	49.0	52.5	47.0	80
XX combined	55.5	60.0	52.5	56.0	60.5	53.5	51.0	54.5	48.0	46.5	50.0	43.5	34
All points on road	61.5	67.5	57.5	61.0	66.5	57.0	56.0	62.0	52.0	49.0	55.0	46.0	291
All points off road	58.5	63.5	55.5	59.0	63.0	55.5	53.3	58.0	50.5	48.5	53.0	46.0	249

A = A road, predominantly through traffic.

B = B road, through traffic, local traffic and bus routes.

D = D road, local traffic, no buses.

E = Open space.

XX = Off road, shielded from noise from the road by buildings, walls, etc.

Table 2.10 Results from the London noise survey - continued.

area-type	7am - 10am 4pm - 7pm			10am - 4pm			7pm - 12pm			12pm - 7am		
	L _{A50}	L _{A90}	L _{A10}	L _{A50}	L _{A90}	L _{A10}	L _{A50}	L _{A90}	L _{A10}	L _{A50}	L _{A90}	L _{A10}
Residential	59.8	65.2	56.0	59.5	65.1	55.7	54.8	60.5	50.7	47.8	2.7	44.9
Industrial	60.9	65.6	57.5	61.7	66.6	58.9	53.8	58.7	50.5	49.4	53.5	46.3
Shopping	64.7	70.5	60.6	64.3	69.9	60.9	60.1	66.1	55.5	52.4	58.2	48.3
Railway	62.0	69.0	58.0	62.3	67.5	57.4	57.0	63.9	52.8	51.0	56.5	47.9
Offices	64.2	69.4	60.7	64.7	68.4	61.7	59.6	64.6	54.9	52.3	58.0	48.4
Open space	60.0	65.0	56.8	59.7	64.3	56.4	55.2	59.9	52.3	49.5	54.0	46.6
Commercial	61.0	65.5	57.9	62.1	65.6	59.0	53.4	58.1	50.7	49.4	53.6	47.2

2.3.2 The 1972 West Midlands Background Noise Survey

In 1972 fourteen West Midlands public health departments undertook an ambient noise survey of the West Midlands to determine the general background noise levels within the conurbation. Values of L_{A90} were calculated from 200 spot readings of sound pressure level dB(A) taken between the hours 10am. to 12am. or 2pm. to 4pm. (daytime), 7pm. to 10pm. (evening), and 2am. to 4am. (night). The sample sites were located at the nodes of a 3 km. grid throughout most of the West Midlands conurbation.

Each of the sites were classified according to the area-types used in BS 4142. The results from the noise survey were published by Gilford and Norris (GIL 73).

Table 2.7 shows the noise levels in each of the BS 4142 categories. The results from the noise survey also showed that at 73% of the sites traffic was the most prominent source of noise. Industrial noise predominated at 17% of the sites. The other sources of most prominent noise were: construction site noise (6%), children and people (6%), domestic noise (5%), birds (4%), trains (4%) and miscellaneous sources such as running water, airport noise, shops and ventilation fans (0.3% each).

2.3.3 Survey of Noise Outside Homes in England

The Transport and Road Research Laboratory (TRRL) undertook a survey of $L_{A10,18hour}$ and $L_{Aeq,18hour}$ noise levels outside homes in England in 1972 (HAR 77). The purpose of the survey was to establish the impact of traffic noise on private homes in England. One hundred and fifty local authority areas were selected, representing eight regions and within each region five groups of population densities.

The survey found that there was no difference between the noise levels in the different regions except for London, which was about 7 dB(A) noisier on average than the other regions. Outside of London, the average $L_{A10,18hour}$ noise levels varied systematically with population density. However, the variation in the average noise levels was best explained by variations in average traffic flow and distance to the road. Even after making allowances

Table 2.11 Noise exposure in England by region

Region	Number of measurement sites	Mean value of $L_{A10,18hour}$	Standard deviation about the mean (dB(A))
London	60	63.6	7.2
South East	71	56.5	5.6
East Anglia	72	56.5	5.2
South West	48	53.1	7.9
Midlands	79	53.4	7.0
South Yorkshire	68	57.1	7.0
North East	36	54.6	7.9
All regions	529	57.0	7.6
All regions except London	469	56.2	7.7

for the higher traffic levels in London, sound levels were still approximately 6 dB(A) noisier than in other conurbations. This difference was thought to be due to the effect of major traffic routes in London.

Tables 2.11 and 2.12 give the mean $L_{A10,18hour}$ noise levels measured in the eight regions studied and in three population densities respectively.

2.4 Conclusions from the Review of Noise Prediction Models

The literature review indicates that ambient levels of the noise indices L_{A10} , L_{A50} , and L_{A90} can be predicted successfully using area-based noise prediction methods. In addition to these variables it is also indicated that the L_{Aeq} index can also be predicted although no model has been developed from measured values of this index. The varying degrees of prediction accuracy between the various previous models is largely due to whether the average noise within an area (POC 79) or the noise at a specific point is being predicted (PRA 78 and ATT 76a). Where average noise levels are predicted within a single region the model can have a standard error of estimate as low

Table 2.12 Noise exposure by population density

Population density classification *	Geometric mean of population density interval (persons/ha)	Median level of $L_{A10,18hour}$	Median level of $L_{Aeq,18hour}$
<i>Conurbations</i>			
London conurbation	-	63	61
Conurbations excluding London	-	55	53
<i>Excluding Conurbations</i>			
25 or more persons/ha	25	55	57
1.5 or more persons/ha but less than 25	6	53	54
0.6 or more persons/ha but less than 1.5	0.9	49	50

as 1.6 dB(A) for L_{A90} or 1.8 dB(A) for L_{A10} (POC 79). Where there is more than one region in the study area it may be necessary to include regional correction factors in the model (ATT 76a) particularly for the London area (HAR 77).

The previous prediction models use land use as the basic predictor variable indicating the type of activity in an area. In addition to this variable, some models include another variable which indicates the degree of activity within the area, namely: population density (PRA 78 and KUN 84), or road network density (POC 79).

Population density such as that available from the national census is obtained for the population at midnight. Therefore, this variable can only be used to indicate the housing density in residential areas. It can not be used to indicate the degree of activity in non-residential areas. The network density variable is a good indicator of the degree of activity within an area and may also give an indication of the contribution that traffic makes to the area's noise levels. However, this network density variable, defined by Pocock, is dependent upon the design of the road network. This design may vary considerably between different areas especially between old and new town developments. As a result the network density variable may not be a good indicator of the degree of activity on a national scale.

The importance of road traffic as a source of noise in urban areas is indicated by the results from the London Noise Survey (GLC 65) and from the West Midlands Noise Survey (GIF 73). It is hypothesised that a national model for predicting noise in both urban and rural areas will require a predictor variable which is an indicator of this important source of noise.

The current area-based prediction method for L_{A90} presented in BS4142 overestimates the background noise levels.

2.5 Evaluation of Area-based Methods of Predicting Air Pollutants

Area-based methods have been developed to predict a variety of air pollutants, including:

1. Mean winter smoke (WOO 74)
2. Mean summer smoke (WOO 74)
3. Mean winter sulphur-dioxide (WOO 74 and POC 79)
4. Mean yearly sulphur dioxide (WEA 75)
5. Carbon monoxide (MYR 76)
6. Total suspended particulate (ROB 77)
7. Nitrogen dioxide (ROB 77)

The models either predict ambient air pollution levels (WOO 74, WEA 75 and POC 79) or the contribution made by types of sources, e.g. automobiles to the ambient concentrations (MYR 76 and ROB 77). Area source prediction models assume that the distribution of area source pollutant emissions is uniform throughout the defined area.

A number of researchers have developed area-based models for predicting air pollution levels. The principal models are:

- area source models that have no diffusion term, often called 'box models' such as that developed by Gifford and Hanna (GIF 73).
- area source models with a diffusion term such as the Climatological Dispersion Model (CAL 71) and the Urban Diffusion Model presented by Miller and Holzworth (MIL 67).
- area source models derived from regression analysis of demographic variables against the dependent air pollution variable (WOO 74 and WEA 75) and independent of air pollution dispersion theory.

The 'box models' are usually confined to urban areas where the urban area is divided into grid squares or uniform blocks. The source strengths within each square or block are assumed to be homogeneous, but different blocks have different source strengths.

Myrup and Rogers (MYR 76) and Pocock (POC 79) used the simple Gifford and Hanna dispersion model (GIF 73) shown in Equation 2.2.

$$c = A \frac{Q_c}{U} \quad (2.2)$$

Where:

- c is the air concentration of a non reactive pollutant in ppm
- A is a stability factor
- Q_c is the local area source strength
- U is the average wind speed in m/s.

Pocock used the Gifford and Hanna model to derive typical levels of sulphur dioxide which were then used to calibrate his two dimensional prediction matrix as defined in Section 2.2.1.

For most low-level and medium-level sources, the air pollutant will diffuse to the ground well before it diffuses to the top of the mixing layer. In these situations the concentration at ground level rises well above that predicted by the 'box models' which assume the pollution is uniformly mixed throughout the whole of the mixing layer.

The Miller and Holzworth model (MIL 67) assumes constant emission strengths everywhere within a city area, and permits vertical mixing only up to the top of the mixing layer. The expected average concentration, scaled to the average emission rate, is determined by wind speed, the size of the model city and the mixing layer depth; thus the prediction can be read (by interpolation) directly from a single tabulation for each specific city.

Robson (ROB 77) used the urban diffusion model derived by Holzworth and Miller (HOL 67).

Wood *et al.* (WOO 74) developed linear equations for predicting ambient air quality which were derived solely from simple and multiple regression analysis of demographic and air pollution data within an area.

Most of the previous prediction models derive an emission rate for demographic variables or categories, the study area is then characterised in terms of these demographic variables and the appropriate emission rates fed into an air pollution dispersion model (MYR 76, ROB 77 and POC 79).

Area-type Classification

Wood *et al.* (WOO 74) found that the mean winter smoke concentration 1965/6 (g/m^3) in each local authority in the Greater Manchester area could be predicted by the following variables:

1. Population/acre alone,
2. Total employment/area alone,
3. Employment in Standard Industrial Classification (SIC) Orders two to eighteen²/area and the number of cars/1000 authority population,
4. Population/acre and the percentage of premises smoke controlled.

Wood *et al.* also found that the mean summer smoke concentration (g/m^3) in 1966 could be predicted by the percentage of SIC Orders 2-18 found within each local authority and that the mean winter sulphur dioxide concentrations 1965/6 (g/m^3) could be predicted by the number of cars/1000 authority population or by the employment in SIC orders 2-18/acre alone.

Clearly the relationship between winter sulphur dioxide and the number of cars/1000 authority population is not a causal relationship as vehicle exhaust contains only a small proportion of sulphur dioxide. Despite the large number of vehicles in Greater London, it has been estimated that vehicle emissions only constitute 3% of the sulphur dioxide emissions in the Greater London area (BAL 79). The national U.K. annual quantity of

²SIC Orders 2-18 are the industrial employment categories defined by the Central Statistics Office (CSO 72)

sulphur dioxide produced from vehicles is 0.046 M tonnes (1973) compared with 2.73 M tonnes (1976) produced from burning coal (DIX 81).

Wood *et al.* found that measured levels of traffic pollutants were generally not well correlated with demographic variables.

Warren Spring Laboratory research (WEA 75) has shown that there is a good correlation between the total domestic emissions of smoke and both mean urban smoke and mean urban sulphur dioxide concentrations. They also found that there is no correlation between mean ground level concentrations of sulphur dioxide at urban sites and the total emissions of sulphur dioxide. This is due to the relative importance of low level emissions from domestic sources, such as burning of fossil fuels, in determining ground level concentrations of smoke and sulphur dioxide rather than high level emissions of sulphur dioxide and smoke from industrial or commercial sources.

Myrup and Rogers (MYR 76) generated area automotive emission rates for the twelve land use categories shown in Table 2.13 for the year 1971.

Robson (ROB 77) used population density as the main predictor variable for predicting the total suspended particulate and nitrogen dioxide. Emission rates per capita are derived from USA national data.

Pocock's model (POC 79) for predicting air pollution had the same predictor variables as the 1979 noise prediction model described in Section 2.2 of this chapter.

Calibration of the Predictive Models

Wood *et al.* (WOO 74), Weatherley *et al.* (WEA 75) and Pocock (POC 79) all used data from the National Survey of Smoke and Sulphur Dioxide to calibrate their prediction models.

Myrup and Rogers model (MYR 76) for predicting carbon monoxide used emission factors published by the US Environmental Protection Agency (EPA 72), land usage taken from local plans, street lengths measured from local maps and vehicle volume data obtained from the Sacramento Traffic Engineer. Measured levels of carbon monoxide were not used to verify the air pollution dispersion model.

Table 2.13 Myrup and Rogers Land Use Categories

Category	Description
Light density residential	Single family unit dwelling (8 family units per acre limit)
Medium-density residential	Multiple family unit dwelling apartments (58 family units per acre limit)
Heavy-density residential	Dense apartment area, boarding house type (87 family units per acre limit)
Shopping-commercial	Shopping centres, individual retail stores, repair shops, limited fabrication-manufacturing.
Office buildings	High rise professional office building area
Central business district	Down town area, department stores, older office buildings and concentrated business activities
Heavy industrial	Industrial park, manufacturing fabrication, distribution centres
Schools	Designated schools and grounds
Water	Rivers, lakes
Seasonal green	Agricultural areas
Open green	Undeveloped areas with natural annual grass and weed cover
Park	Designated parks, maintained year-round

Table 2.14 Data sources used by Robson

Variable Description	Source
Estimates of the total rate of pollutant emission	EPA (EPA 72)
City populations in 1970.	City and County Data Book (1972).
Metropolitan, city area in 1970.	City and County Data Book (1972).
Fraction of work-force using public transport to commute to work in 1970.	City and County Data Book (1972).
Mean annual temperature of sample area.	City and County Data Book (1972).
The ratio of population increase between 1920 & 1950 to that in 1950.	Bogue (1956). (BOG 56)
Predicted ratio of average concentration to the uniform rate of emission per unit area.	Holzworth (1972). (HOL 72)

Robson's model was calibrated using unpublished United States Environmental Protection Agency (EPA) measurements of particulates and nitrogen dioxide in metropolitan areas. The variables used in the model are shown in Table 2.14 along with the sources of data.

Pocock used data from the Warren Spring Laboratory national survey of smoke and sulphur dioxide to calibrate the Gifford and Hanna air pollution dispersion model. The resultant air prediction model was used to derive an ambient sulphur dioxide levels for each 1.25 km² square within the West Midlands area and to calibrate the prediction matrix.

Model Performance

The performance of Wood *et al's*. predictive models for air pollution are summarised below (the figures in brackets are the corrected student T test values for each variable coefficient).

$$\begin{array}{rclclcl}
Pa_{10} & = & 150 & + & 3.7S_4 & & r = 0.46 & \alpha = 0.0025 \\
Pa_{10} & = & 160 & + & 5.3I & & r = 0.40 & \alpha = 0.01 \\
Pa_{10} & = & 180 & + & 14C_1 & & r = 0.50 & \alpha = 0.0025 \\
Pa_{10} & = & 173 & + & 9.1C_1 & - & 0.45S_6 & \\
& & (11.6) & & (2.6) & & (1.1) & \bar{R}^2 = 0.13 \\
Pa_{10} & = & 158 & + & 4.2S_4 & - & 0.57S_7 & \\
& & (9.3) & & (3.0) & & (1.4) & \bar{R}^2 = 0.18
\end{array}$$

Where:

Pa_{10} = winter 1965/6 average smoke concentration (g/m³)
 S_4 = population/acre
 S_6 = number of cars/1000 authority population
 S_7 = percentage of premises smoke controlled
 I = total employment/acre
 C_1 = employment in SIC Orders 2-18/acre
 r = the Pearson correlation coefficient
 α = significance from the student t test
 \bar{R}^2 = the percentage of variance explained after adjustment for degrees of freedom

$$Pa_{11} = 15 + 0.079S_5 \quad r = 0.57 \quad \alpha = 0.0005$$

Where:

Pa_{11} = summer 1966 average smoke concentration (g/m³)
 S_5 = socio-economic grouping index
 r = the Pearson correlation coefficient
 α = significance from the student t test

$$Pa_{20} = 350 + 0.88S_6 \quad r = 0.61 \quad \alpha = 0.0005$$

Where:

Pa_{20} = winter 1965/6 average SO₂ concentration
(g/m³)
 S_6 = number of cars/1000 authority population
 r = the Pearson correlation coefficient
 α = significance from the student t test

Weatherley *et al.* (WEA 75) do not give the standard error of estimate for the prediction model given in Equation 2.3.

$$y = 147.2x \times 6.8 \quad (2.3)$$

Where:

y is the yearly mean of daily smoke concentrations ($\mu\text{g}/\text{m}^3$)
 x is the tons of domestic coal burnt per capita

Warren Spring Laboratory also found that there is a relationship between mean urban concentrations of sulphur dioxide and coal consumption i.e. that the concentration increase by approximately 15 $\mu\text{g}/\text{m}^3$ for every 100 kg. of domestic coal used per head of population. However, the London and Wales regions are anomalous probably due to the low sulphur content of the fuels burnt in these regions.

The Myrup and Rogers model for predicting carbon monoxide is not validated using measured levels of carbon monoxide but the predicted values are of the correct order.

Robson gives no indication of the models accuracy or validity.

Pocock's prediction matrix for mean winter sulphur dioxide concentrations gives a standard error of estimate with the range 8.7 to 17.7 $\mu\text{g}/\text{m}^3$.

A few researchers have used the relationship between demographic characteristics and air pollution levels to develop models for predicting land use or source strengths from air pollution measurements. Legrand's statistical study of smoke and sulphur dioxide over five urban areas in Belgium

Table 2.15 Statistical results of sulphur dioxide levels measured at four sites (LEG 74)

Station Number	Median SO ₂	Slope SO ₂	Station Type
810	288	0.18	urban
812	158	0.28	suburban
823	114	0.23	rural
826	252	0.29	industrial

(LEG 74) concluded that the slope of the years daily measurement frequency distribution curve (plotted on a logarithmic scale) and the median of these values could be used to develop a model that would distinguish between different urban, suburban, rural and industrial areas. The sulphur-dioxide results from four such sites are given in Table 2.15. The results show that the median sulphur dioxide concentrations are highest in urban and industrial areas and the variability in concentrations is highest in industrial and suburban areas.

Draxler (DRA 87) used measured air concentrations of a tracer gas emitted from two different locations and dispersion factors to estimate the emissions of the tracer gas.

2.6 Evaluation of Area-type Classifications Used to Present Air Pollution Data

Warren Spring Laboratory used land use categories to differentiate between different levels of smoke and sulphur dioxide (winter and summer means) and between different levels of deposited grit and dust (annual mean), for measurement sites throughout the United Kingdom. They found that mean winter concentrations of smoke and sulphur dioxide were related to land use. Three land use classification systems were used.

The first and simplest land use classification system used two categories: country site and town site. The second used the national air pollution survey

site classifications listed in Section 3.3.4. In the North, North West, East Midlands and East Anglia the variations in mean winter smoke levels were further explained by including a variable indicating whether the monitoring site was in an area subject to a smoke control order .

The third classification system was used to examine both mean winter and mean summer concentrations of sulphur dioxide and smoke. Seven area-type categories were used to classify each of the air pollution monitoring sites:

- L/O - Lower-density housing areas with at least 25% open ground.
- L - Other lower-density housing areas.
- H - High-density housing areas.
- CZ - The central zone³.
- I - Mainly industrial.
- C/H - Commercial sites with densely populated areas (and not within the central zone).
- C/M - Commercial sites within areas of lower-density housing or mixed-density housing areas.

In Greater London it was found that further subdivisions of site classifications, e.g. to distinguish between high-density population sites within and outside smoke control areas, or between industrial sites including different types of housing, have no effect whatsoever on the explanation of spatial variations in measured smoke concentrations.

In Greater London, mean-winter and mean-summer concentrations of smoke showed a slight negative correlation with the height above sea level. In Sheffield, neither the peak levels nor the ratio of peak to winter-mean levels of smoke or sulphur dioxide showed any relationship with height above sea level.

³i.e. The city centre.

In the Warren Spring Laboratory study of the effect of local surroundings on the annual average deposition of dust and grit in London (1958 to 1959), the national survey of air pollution classifications were amended so that the central zone sites had a separate classification. The result was that no distinction was drawn between deposit gauges measuring specific sources and those measuring general deposits.

The monitoring site classification systems explored by the Warren Spring Laboratory were not presented as prediction techniques but do indicate a potential to develop area-based prediction techniques for smoke, sulphur dioxide and deposited grit and dust.

The Warren Spring Laboratory used air pollution measurements and land use details obtained from the national survey of air pollution (1961 to 1971) to calibrate their classification systems. However, it is unclear where they obtained the data required to re-classify the monitoring sites in Greater London and Sheffield as they are not derived from subsets of the national survey data classifications.

Bar-charts published by the Warren Spring Laboratory (WSL 72) indicate the degree of differentiation between pollution levels and the range of values in each of their area classifications. The bar-charts are reproduced in Figures 2.1 to 2.7.

It can be seen that there is considerable overlap between pollution levels in different area-type classifications. In the case of London smoke, approximately 60% of the mean winter concentrations and 50% of the mean summer concentrations at individual sites within an area-type lie within 20% of the median seasonal mean for that area-type. For London sulphur dioxide concentrations, 70% of winter or summer mean measurements lie within 20% of the median value for the area-type. In Sheffield, there is little difference between smoke levels in each of the land use categories. In general, the range of pollution levels in each category is narrower in the summer period than in the winter period for measurements of both smoke and sulphur dioxide.

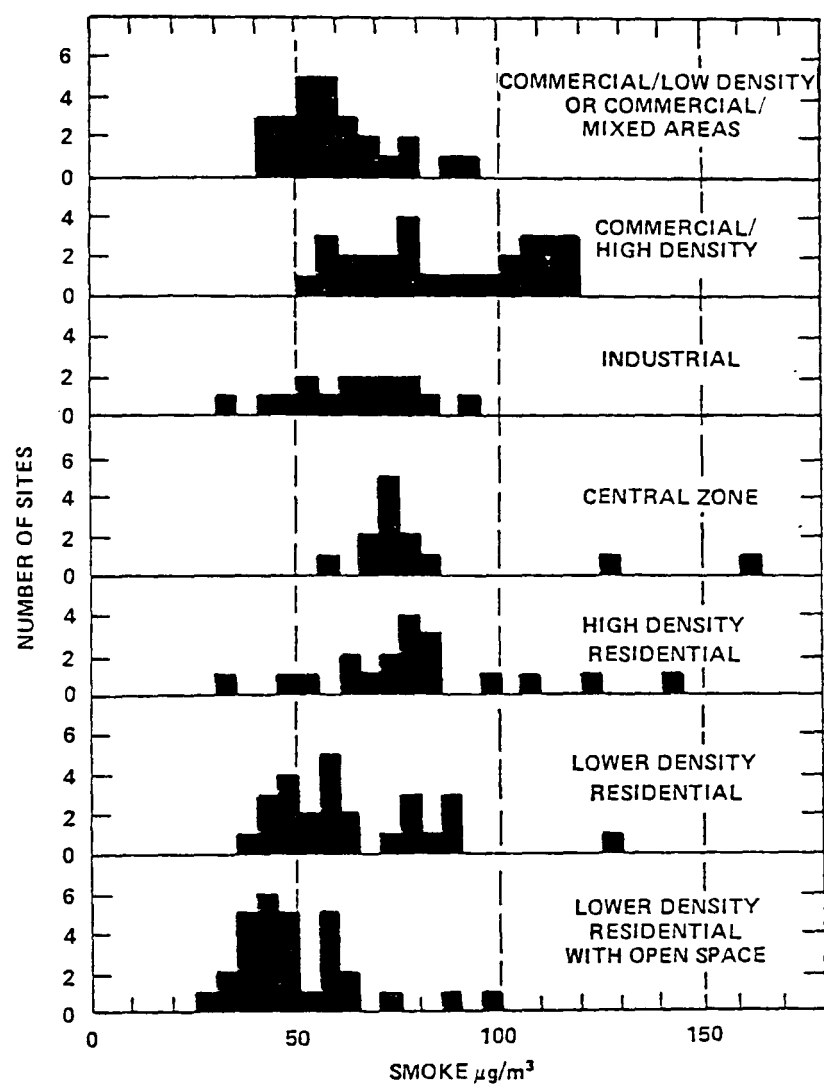


Figure 2.1 Distribution of average smoke levels at different types of site in London, Winter 1966-7 (WSL 72).

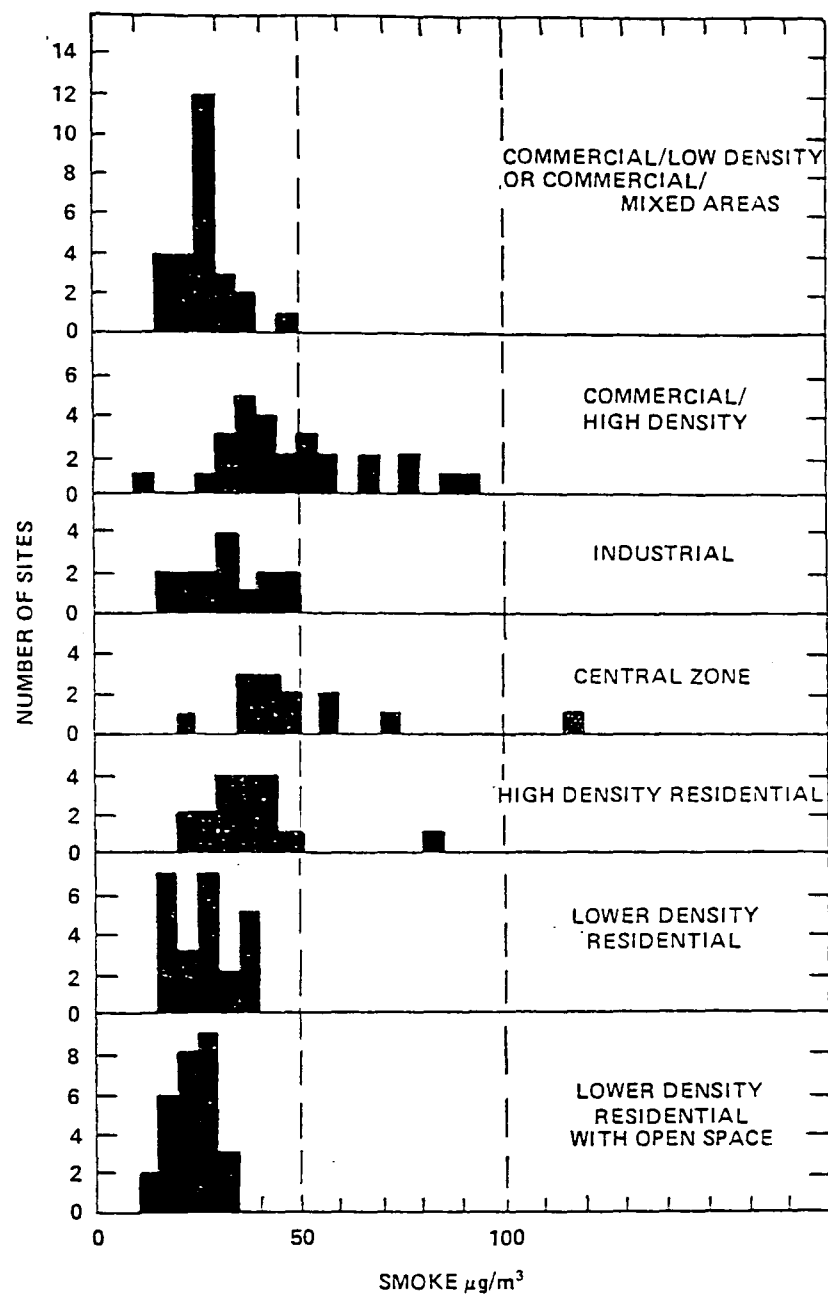


Figure 2.2 Distribution of average smoke levels at different types of site in London, Summer 1966 (WSL 72).

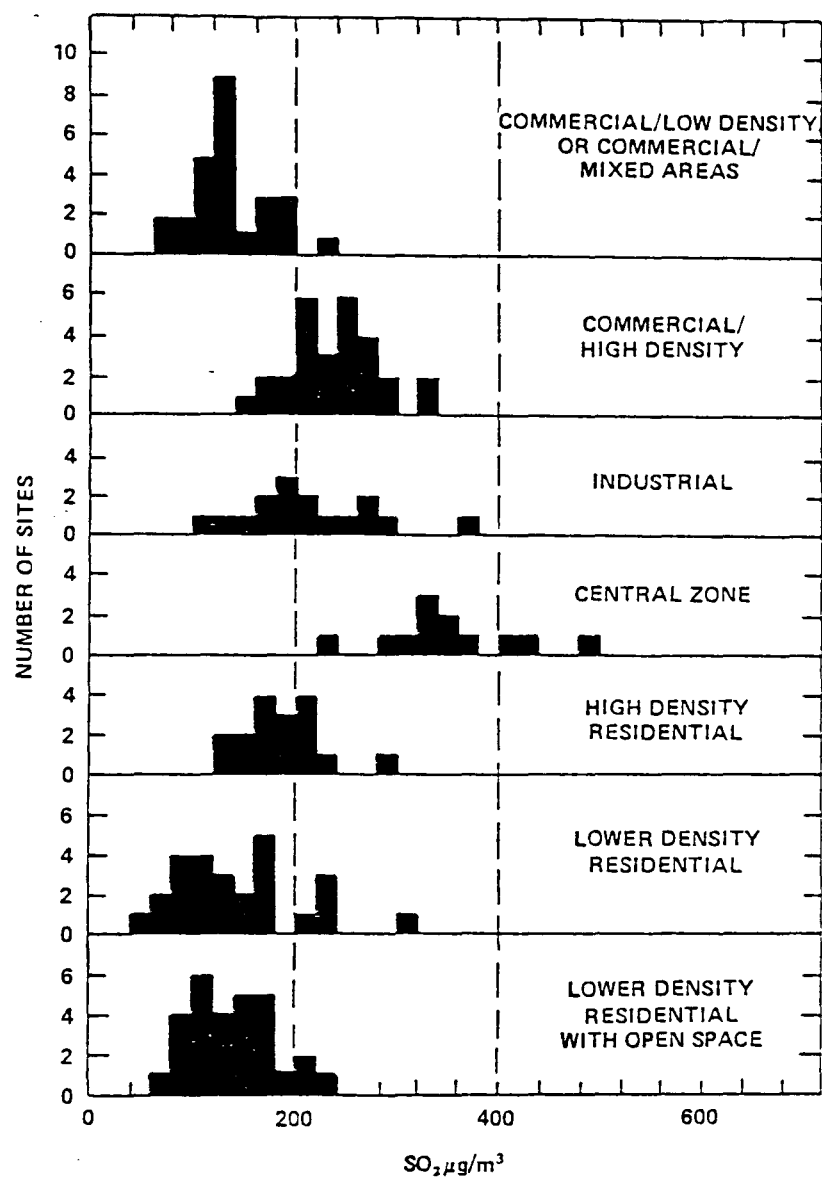


Figure 2.3 Distribution of average sulphur dioxide levels at different types of site in London, Winter 1966-7 (WSL 72).

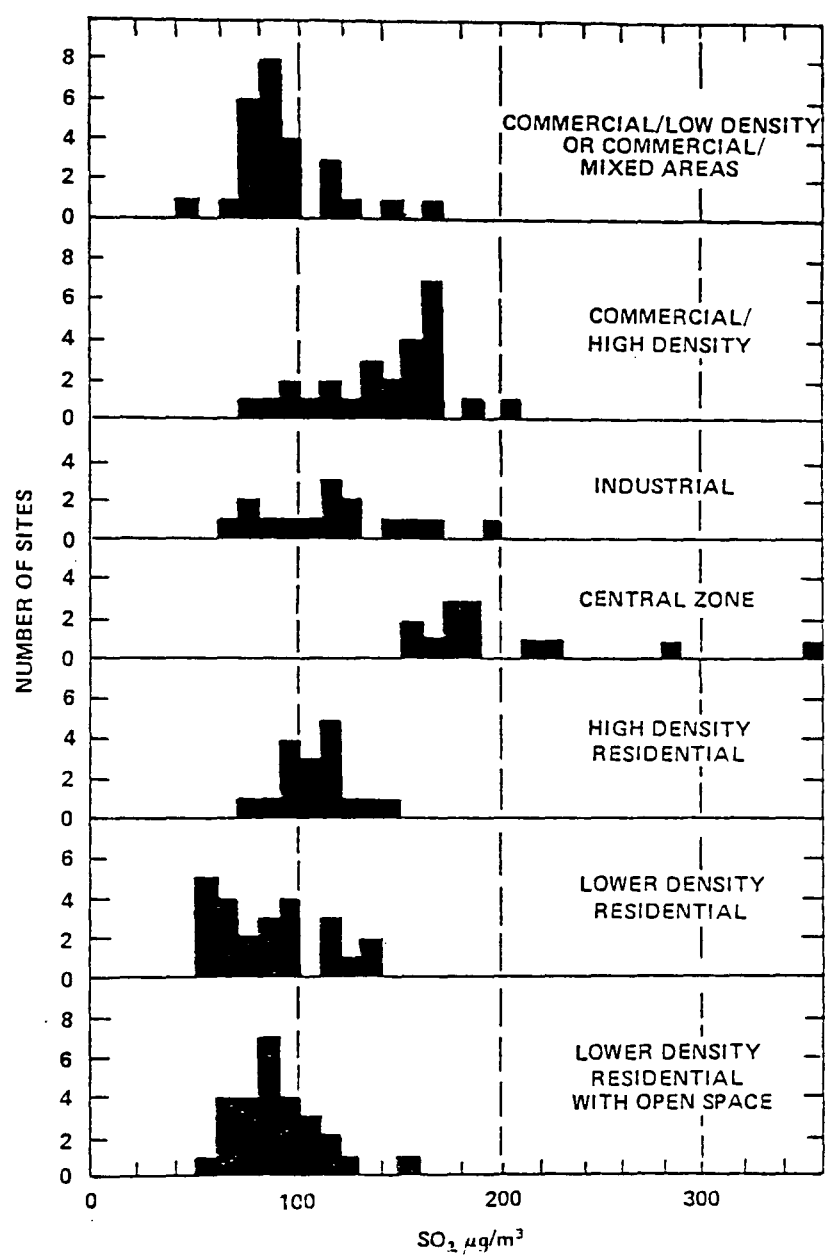


Figure 2.4 Distribution of average sulphur dioxide levels at different types of site in London, Summer 1966 (WSL 72).

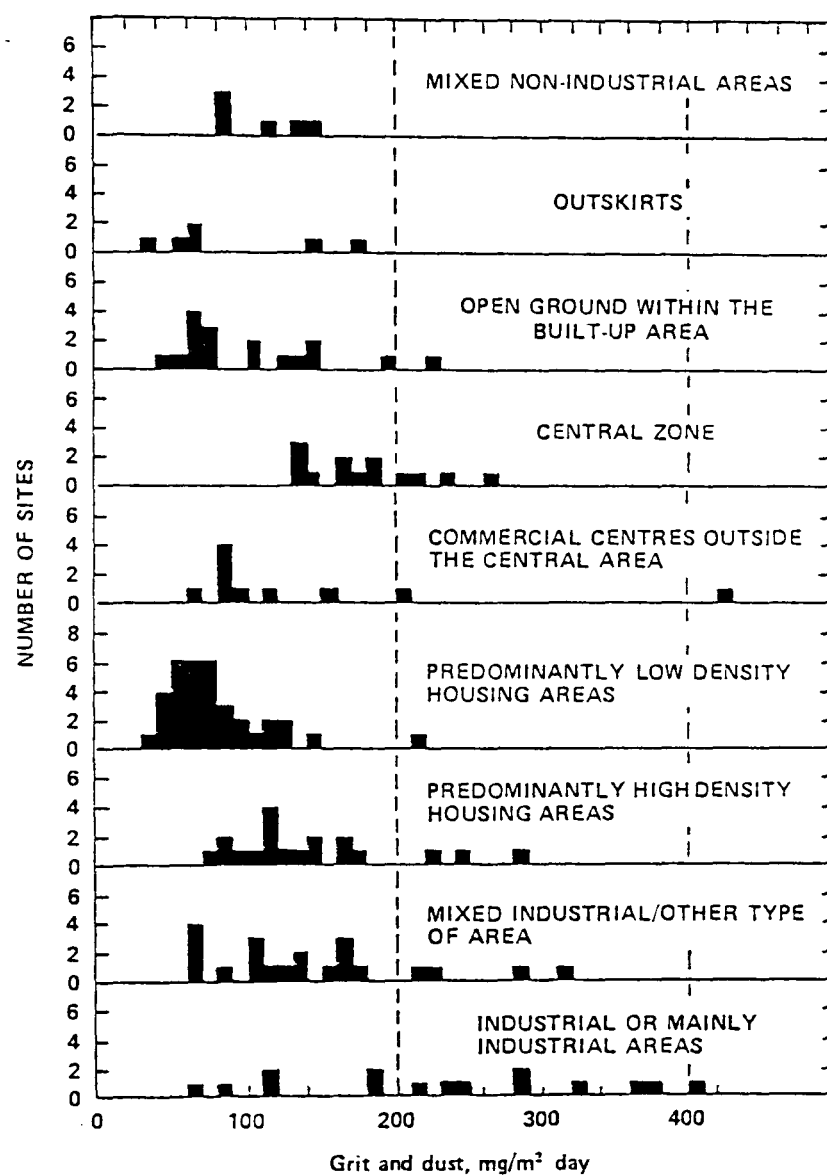


Figure 2.5 Distribution of annual average levels of grit and dust at different types of site in London, 1958-9 (WSL 72).

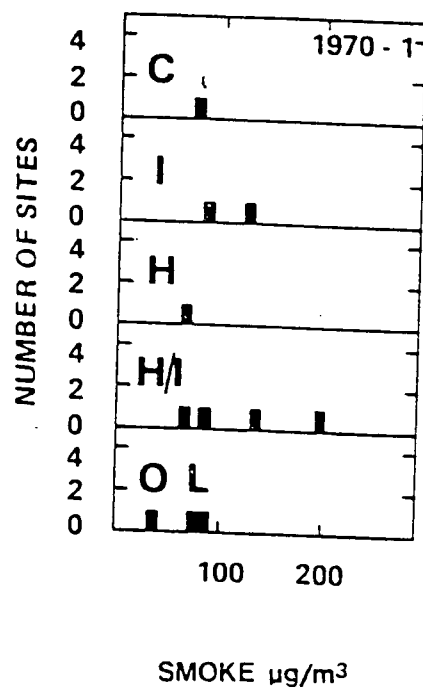


Figure 2.6 Distribution of average smoke levels at different types of site in Sheffield, Winter 1970-1 (WSL 72).

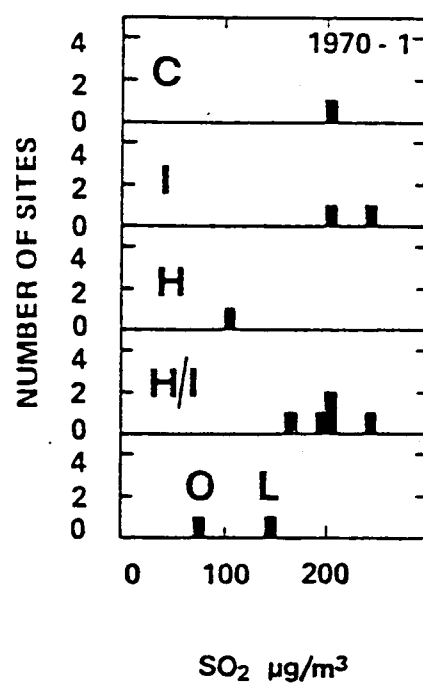


Figure 2.7 Distribution of average sulphur dioxide levels at different types of site in Sheffield, Winter 1970-1 (WSL 72).

2.7 Summary and Conclusions from the Air Pollution Prediction Model Literature Review.

Previous research in the field of air pollution prediction indicates that both sulphur dioxide and smoke concentrations can be predicted using demographic variables. However, very few researchers have quantified the accuracy of these prediction models. The research carried out by Pocock (POC 79) indicates that, on a regional scale, winter sulphur dioxide concentrations can be predicted with a standard error of estimate of between $8.7 \mu\text{g}/\text{m}^3$ and $17.7 \mu\text{g}/\text{m}^3$.

Land use plays a central role most of the air pollution prediction models. The theoretical relationship between air pollution and land use is based on causal factors. However, the Warren Spring Laboratory research (WSL 72) indicates that this parameter alone may not be sufficient to distinguish between spatial variations in air pollution levels.

A number of researchers have used predictors which do not have a direct causal relationship with air pollution concentrations but do indicate the degree of land use or activity within an area. These demographic variables are road network density (POC 79) and population density (WSL 72, WOO 74 and ROB 77).

The most comprehensive research into the spatial distribution of air pollution on a national scale within the United Kingdom and the relationship with demographic variables is that presented by Warren Spring Laboratory (WSL 72). However, the research lacks rigorous statistical analysis. Perhaps the most surprising finding of their research is that whether an area is subject to smoke control only helps to explain the spatial variations in smoke in the North, NorthWest, East Midlands and East Anglia regions. This may be explained by the influence of vehicle exhaust on smoke concentrations in other regions as described by Ball and Hume (BAL 77).

Chapter 3

Experimental Design

3.1 Selection of Pollutants

The number of pollutants, against which the fundamental research hypothesis can be tested, is limited by the operational constraints of the research.

Initially it was hoped that several pollutants representing each of the commonly accepted media-based pollutant classifications, i.e. Air, Land, Noise and Water, might be used to test the hypothesis.

As discussed in Chapter 1:

- Water pollutants have been excluded since area-based prediction methods are inappropriate for their prediction and
- Land pollution is excluded since contamination data are not available in a comprehensive form and, moreover, the gathering of such data is likely to be impractical.

While air pollution data are available for a small number of pollutant species in sufficient quantity to allow, in principal, the testing of the fundamental research hypothesis, the data supplied by the Warren Spring Laboratory, and discussed in Appendix C, have one major deficiency. Each measurement site is classified into one of fourteen land use categories. The classification seems to be based on subjective assessment for an unspecified spatial unit and may therefore provide only a qualitative basis for testing the hypotheses of this research. To gather objective demographic data for such

widely distributed measurement sites is too great a task within a doctoral project. As a result, although air pollutants are used to test the hypothesis, the limitations of the land use data available prevents an air pollution model from forming the main thrust of the research.

Instead, noise pollution data and more accurate land use data are used to develop and test a corresponding predictive model for ambient noise. The data have been obtained from a noise survey carried out in areas where comprehensive and rigorous land use data are available.

Noise measurements and land use data that have been obtained in a less accurate and rigorous manner but, geographically, are of a more widespread nature are also used to explore some aspects of the research. These data were supplied by students taking the Open University course 'T234: Environmental control and public health' in 1985 - 1986 (see Appendix A).

As well as the model development and testing using the noise pollution data and more accurate land use data, the Warren Spring Laboratory air pollution data have been used to explore the possibilities of extending the area-based model to predict air pollutants.

It is necessary to select the type of air or noise pollution for which the model is to be developed and tested and to decide upon the measures that represent such pollution.

The following criteria are relevant:

1. Previous research and/or theoretical reasoning should indicate that the pollutant(s) and indices of measurement are predictable using area-based methods.
2. The predicted pollutants and their measures should be of interest to those for whom the model is intended.
3. There should be sufficient pollutant data available, supported by the relevant demographic information, to allow the predictive model to be developed.
4. The number of pollutant variables to be predicted should be limited

to a number appropriate to the length and resources of the doctoral project.

3.1.1 Selection of Noise Indices for Prediction

L_{Aeq} , L_{A10} , and L_{A90} noise indices, measured in A-weighted decibels, are widely accepted as good descriptors of ambient environmental noise pollution. They are of particular interest to planners. Other noise indices such as TNI can be described using these quantities.

L_{Aeq} is recommended by the International Organisation for Standardisation (ISO 82) for measuring and rating noise in residential, industrial, and traffic areas.

The individual indices, L_{A10} and L_{A90} , represent peak and background noise levels respectively. $L_{A10,18hour}$ is primarily used to measure traffic noise (DOE 75). L_{A90} is used in the rating of industrial noise (BSI 67).

The difference between L_{A10} and L_{A90} ($L_{A10}-L_{A90}$) indicates the degree of variation in noise levels and maybe linked to public annoyance (GRI 68).

The A-weighted 'upper noise limit'¹ (UNL), 'lower noise limit'² (LNL) and L_{A90} indices and a calculated $L_{Aeq,5mins.}$ value derived from UNL and LNL have been used successfully by previous researchers to produce prediction models (ATT 76a and POC 83). Pocock's derived $L_{Aeq,5mins.}$ was calculated using the following equation:

$$L_{eq,5mins.} = 10 \log_{10} \left[\frac{1}{100} [16(10^{\frac{L_1}{10}}) + 34(10^{\frac{L_2}{10}}) + 34(10^{\frac{L_3}{10}}) + 16(10^{\frac{L_4}{10}})] \right]$$

where:

$$\begin{aligned} L_1 &= \frac{UNL-LNL}{2} - \frac{3}{2} \left(\frac{UNL-LNL}{2.58} \right) \\ L_2 &= \frac{UNL-LNL}{2} - \frac{UNL-LNL}{2.58} \\ L_3 &= \frac{UNL-LNL}{2} + \frac{UNL-LNL}{2.58} \\ L_4 &= \frac{UNL-LNL}{2} + \frac{3}{2} \left(\frac{UNL-LNL}{2.58} \right) \end{aligned}$$

¹A measure of average peak noise level derived from visually averaging the upper deflections of the sound level meter's needle and which approximates to the L_{A10} index.

²A measure of the background noise derived from visually averaging the lower deflections of the sound level meter's needle which approximates to the L_{A90} index

This equation is an approximation of the equation for calculating the L_{Aeq} for fluctuating noise (Equation 3.1) and assumes a normal distribution of noise levels.

$$L_{eq,T} = 10 \log_{10} \left(\frac{1}{100} \sum p_i \cdot 10^{\frac{L_{Ai}}{10}} \right) \quad (3.1)$$

Where:

L_{Ai} is the sound pressure level of the mid point of the time interval i in dB(A).

p_i is the time interval expressed as a percentage of the total time period (T).

The validity of Pocock's derived $L_{Aeq,5mins.}$ is not tested as part of his research. However, other researchers have developed much simpler methods for calculating L_{Aeq} from other noise indices and have found good correlations between the calculated and measured values of L_{Aeq} .

Driscoll *et al.* (DRI 74), Berry (BER 74) and Borruso *et al.* (BOR 79) found that L_{Aeq} can be estimated from L_{A10} . Berry *et al.*'s model predicted $L_{Aeq,18hours}$ from $L_{A10,18hours}$. No measurement time period is given for the relationships derived by Driscoll *et al.* Borruso *et al.* also found that $L_{A90,10mins.}$ could be used to predict $L_{A10,10mins.}$ although it was a much poorer predictor.

Berry analysed results from a large scale noise survey of traffic noise (NAG 71), Driscoll *et al.* studied 14 different distributions of road traffic noise and Borruso *et al.* studied traffic noise with widely varying characteristics which were selected from a previous study by Delany *et al.* (DEL 71).

The models for predicting a L_{Aeq} from a single noise index were derived by calculating the mean difference between the predictor and the predicted.

The models resulting from these studies are given in Table 3.1 along with the standard deviation (T) of the difference between the calculated L_{Aeq} and the true L_{Aeq} .

Borruso *et al.* (BOR 79) also found that $L_{Aeq,10mins.}$ could be predicted from $L_{A10,10mins.}$ and $L_{A90,10mins.}$ when assuming a Gaussian distribution of

Table 3.1 Relationships between individual noise indices

Model Formula	Standard Deviation T	Reference
$L_{Aeq,T} = L_{A10} - 3.6$	0.8	Driscoll <i>et al.</i> (DRI 74)
$L_{Aeq,18hour} = L_{A10} - 2.7$	1.4	Berry (BER 74)
$L_{Aeq,10mins.} = L_{A10} - 2.9$	0.72	Borruso <i>et al.</i> (BOR 79)
$L_{Aeq,10mins.} = L_{A90} + 6.2$	3.04	Borruso <i>et al.</i> (BOR 79)

measurements.

The prediction equation based on a Gaussian distribution is:

$$L_{eq,10mins.} = \frac{(L_{10,10mins.} + L_{90,10mins.})}{2} + \frac{(L_{10,10mins.} - L_{90,10mins.})^2}{57} \quad (3.2)$$

The mean difference between the calculated L_{Aeq} and the true L_{Aeq} was 0.02 dB and the standard deviation of this difference (T) is 0.26 dB.

Road traffic is the most widespread and dominant source of noise throughout most areas of Britain. It is thus expected that the relationships found between the noise indices, where road traffic is the major source, are relevant to this research as they indicate that true L_{Aeq} can be predicted using the same techniques for predicting L_{A10} and L_{A90} . However, it is possible that these relationships will not hold where traffic is not the major source of noise e.g. in rural areas where there is no traffic.

Previous research has shown that L_{A10} and L_{A90} can be predicted using area-based methods. The relationships between L_{A10} and L_{Aeq} , and L_{A90} and L_{Aeq} found by Driscoll *et al.* and Borruso *et al.* suggest that it may be possible to predict L_{Aeq} using area based methods. Thus, L_{Aeq} , L_{A10} and L_{A90} are selected as the variables for which the noise model will be developed. Pocock (POC 79) used this hypothesis to develop an area-based prediction model for L_{Aeq} , however, the L_{Aeq} value was calculated as discussed on Page 55. The prediction model for L_{Aeq} developed in this research will be derived from actual L_{Aeq} measurements. The variable $(L_{A10} - L_{90})$ is also selected.

3.1.2 Selection of Air Pollutants for Prediction

The criteria listed in Section 3.1 are used also to select the air pollutants with which to test the area-based prediction of air pollution within the United Kingdom.

The third criterion is decisive in the choice of pollutant as there is only a limited amount of air pollution data available on a national scale within the United Kingdom.

Air pollution monitoring of different types is carried out by various agencies within the United Kingdom, and consequently the data available varies in respect of the pollutant species measured and the quantities recorded.

The most reliable information showing the most complete coverage of air pollution is provided by the National Air Pollution Survey of Smoke and Sulphur Dioxide 1960-1982.

Other monitoring programmes are less extensive and usually involve a small number of sites. They are concerned with a range of different pollutants and particularly hazardous substances such as metals, pesticides, oxidants etc. as shown in Table 3.2.

Due to the irregular temporal variations in air pollution, it is impractical to undertake a large independent survey of air pollution as part of a doctoral project.

The National Air Pollution Survey 1960-1982, had approximately 1300 monitoring sites throughout the United Kingdom. Approximately 1100 sites were located in selected urban areas and there were 200 rural sites to sample the background concentrations of sulphur dioxide and smoke. Regular daily sampling was carried out at each of these sites.

The subsequent United Kingdom Urban Smoke and Sulphur Dioxide Monitoring Network, is smaller in scale initially monitoring 475 sites with much fewer rural monitoring sites.

The National Air Pollution Survey (1960-1982) data for smoke and sulphur dioxide, are also supplied with details of the area-type classification in which the monitoring station is situated along with details of whether the area is subject to smoke control legislation.

Table 3.2 Air Pollution Monitoring in the United Kingdom

Department	Responsibility	Agency
DoE	Smoke and sulphur dioxide Grit and dust Industrial emissions Lead, fluoride, cadmium etc. Metals generally & acidity Motor vehicle emissions	LAs, CEGB & WSL. LAs, CEGB & WSL Industry & HMIP Industry, LAs & HMIP LAs WSL, TRRL
DTI	Nitrogen oxides, oxidants, Hydrocarbons Airports Organo-pesticides in rain and the atmosphere	WSL WSL WSL Laboratory of the Government Chemist
MAFF and DES	Trace elements in rain and soil	NERC, AERE, MAFF
MOD	Chemicals in air and rain	Meteorological Office

AERE = Atomic Energy Research Establishment (Harwell).

CEGB = Central Electricity Generating Board.

DES = Department of Education and Science.

DTI = Department of Trade and Industry.

HMIP = Her Majesty's Inspectorate of Pollution.

LA = Local Authority.

MAFF = Ministry for Agriculture Food and Fisheries.

MOD = Ministry of Defence.

NERC = National Environmental Research Council.

TRRL = Transport and Road Research Laboratory.

WSL = Warren Spring Laboratory.

The availability of data on smoke and sulphur dioxide and supporting land use data, indicates that smoke and sulphur dioxide data from the pre 1982 National Survey of Air Pollution best satisfies the third selection criteria.

Previous research (WOO 74 and POC 79), has shown that both of these pollutants can be predicted using area-based methods of prediction while the 1980 EEC 'Directive on air quality limit values and guide values for sulphur dioxide and suspended particulate' (80/779/EEC), ensure that levels of these pollutants are of current importance in the field of environmental pollution control. This means that these pollutants fulfil the other selection criteria.

3.1.3 Selection of Measures of Smoke and Sulphur Dioxide for Prediction

Measures of smoke and sulphur dioxide are chosen for prediction that correspond to those specified in the EEC directive 80/779/EEC 'Directive on air quality limit values and guide values for sulphur dioxide and suspended particulate.'

The measures of smoke and sulphur dioxide specified in this directive are:

1. The yearly median of daily values.
2. The winter median of daily values (October to March).
3. The yearly 98th percentile of daily values.
4. The yearly arithmetic mean of daily values.
5. The 24 hour daily mean value.

The limit values and guide values specified by the EEC directive 80/779/EEC for these pollutant measures are given in Table 3.3.

Sulphur dioxide is produced primarily from the combustion of sulphur containing fuels. Smoke is also produced from the combustion of these fuels. However, other fuels, such as diesel, containing very little sulphur are

Table 3.3 Limit values and guide values for smoke and sulphur dioxide

Limit values ($\mu\text{g}/\text{m}^3$)		
Reference Period	Smoke	Sulphur Dioxide
Year (median of daily values)	80 (68)	If smoke less than 40:120 If smoke more than 40:80 (34)
Winter (median of daily values)	130 (111)	If smoke less than 60:180 If smoke more than 60:130 (51)
Year (peak) (98th percentile of daily values)	250 (213)	If smoke less than 150:350 If smoke more than 150:250 (128)
Guide values ($\mu\text{g}/\text{m}^3$)		
Reference Period	Smoke	Sulphur Dioxide
Year (arithmetic mean of daily values)	40 to 60 (34 to 51)	40 to 60
24 hours (daily mean values)	100 to 150 (85 to 128)	100 to 150

(Limit values for smoke as stated in the Directive relate to the Organisation for Economic Cooperation and Development (OECD) method: the figures in brackets give the equivalents for the BSI method as used in the National Survey of Smoke and Sulphur Dioxide.)

also important sources of smoke. Table 3.4 gives the approximate sulphur content of fuels used in the late 1970s and early 1980s³. In addition to the burning of fossil fuels there are other processes which can produce significant quantities of sulphur dioxide but which are not such significant sources of smoke, examples are:

- petroleum refining,
- copper smelting,
- lead smelting,
- zinc smelting,
- smokeless fuel production plants and
- coke ovens.

The ratio of winter smoke and winter sulphur dioxide reflects the relative contributions of the different sources of pollution within an area. It is hypothesised that the relative importance of the different sources will vary from one area-type to another. Thus, in addition to the EEC measures, the measure $\frac{Smoke}{SO_2}$, where smoke and sulphur dioxide measures are both winter median daily values (October to March), is also included in the analysis of air pollution data.

This limited selection of pollutants provides a tractable basis for study in this thesis.

3.2 Construction of Theoretical Prediction Model for Noise Pollution

Previous area-based methods for predicting noise, using more than one predictor variable, have adopted either a linear additive or matrix model structure.

³These data are presented rather than more recent data because they relate to the subsequent analysis of air pollution data from this period

Table 3.4 Sulphur content of fuels

Fuel type	Sulphur content (% weight)	Smoke emissions (% weight)	Calorific value GJ/tonne
Fuel oil	3.0	0.1	43.0
Gas oil	0.7	0.025	45.6
Solid smokeless fuel	1.0	0.56	32.9
Bitumen coal	1.3	3.5	27.9
Motor spirit	0.04	-	-
Derv	0.35	-	-
Burning oil	0.1	0.001	-
Gas	0.00	-	-

Sources: (WEA 76, KED 78 and BAL 80).

'Fuel oil' consists of heavy petroleum distillates, residues or blends. It is often used in furnaces for the production of heat and power. Usually, but not always, fuel oils have a higher sulphur content than other fuels.

'Gas oil' is a petroleum distillate having a range intermediate between kerosine and light lubricating oil. It is primarily used as a burner fuel in heating installations.

'Burning oil', also known as paraffin or kerosine, is a refined petroleum distillate intermediate in volatility between motor spirit and gas oil and is used in heating installations.

'Motor spirit' and 'Derv' are light petroleum distillates used as fuel for internal combustion engines using spark ignition and compression ignition respectively.

Linear additive models (ATT 76a, PRA 78, and KUN 84) do not allow for interdependency between the predictor variables. This is a source of error in such models. Since the matrix form does allow for interdependency it is the model form preferred for this research.

The British Standard model (BSI 67) and the Attenborough *et al.* model (ATT 76a) both have an ambiguous method of categorising an area in terms of demographic variables. They predict background noise levels for a single site in an area of undefined scale. When using these models, it is not clear what spatial unit should be considered for categorising an area into one of the area classifications.

Models predicting noise levels for a single site, have a generally lower accuracy than those predicting the average noise level within an area. It is likely that this accuracy could be improved by defining the the spatial scale to which the land use classification applies and by predicting an average noise level for sites in that area.

3.2.1 Selection of a Spatial Scale of Prediction for Noise Pollution

Accuracy of prediction within the area will depend on two conflicting criteria: area homogeneity and noise propagation distance. Area-based prediction methods rely on the concept that noise generated outside of the area, for which the prediction is being made, does not significantly affect the ambient neighbourhood noise level within the area. This will be a function of the distance that sound propagates from 'external' sources. A large area will be least affected by external noise sources. However, the larger the area the more inhomogeneous it will become and the wider the range of noise levels found within it. An area size is required that balances these two criteria.

Senko *et al.* (SEN 71) recommend one square mile (1.6 km²) as a homogeneous sample unit in large urban areas.

Pocock's model predicted levels of noise for each 1.25 km² square within the West Midlands with an accuracy of approximately ± 1.7 dB(A). Many of the demographic statistics which are necessary for development of a pre-

diction model are given for the 1 km² square area e.g. population statistics, land use etc. A 1 km² square unit is therefore a practical spatial unit for data gathering as well as being of the same order of size as the spatial units chosen by Senko *et al.* and Pocock on theoretical grounds.

Although the 1 km² square seems an appropriate spatial scale for predicting noise levels in urban areas, noise will propagate more readily in rural areas. The absence of artificial barriers, such as buildings, and the generally lower background noise levels will result in a rural noise source dominating the prevailing noise level over a wider area than the same type of source in an urban setting. For example a two-storey building can reduce noise levels on the side of the building away from the source by 13 dB(A). A second row of buildings will reduce this level by a further 1 to 2 dB(A) (NEL 87).

The area affected by a motorway in a rural setting can be estimated by using the method set out in 'Calculation of Road Traffic Noise' (DOE 75) although the accuracy of the model declines beyond a distance of 300m over hard ground.

If we consider a rural motorway that is straight, and level, with no barriers, crossing flat terrain, that has an 18 hour vehicle flow (Q) of 77,000 vehicles, a mean vehicle speed (V) of 100 km/hr, and traffic composed of 25% heavy goods vehicles (p), we can calculate the theoretical reference noise level (LT) 10m. from the edge of the carriage way and at a height of 0.5 metres using the equations given in 'Calculation of Road Traffic Noise' (DOE 75):

$$LT = 26.1 + 10 \log Q + C_1 \quad (3.3)$$

Where:

Q is the total 18 hour vehicle flow (0600 to 2400 hours)

$$C_1 = 33 \log(V + 40 + \frac{500}{V}) + 10 \log(1 + \frac{5p}{V}) - 68.8$$

V is the mean traffic speed (km./hr.)

p is the percentage of heavy vehicles in the traffic.

The noise level (LT) for this motorway is 82.8 dB(A) ($C_1 = 7.8$ dB(A)).
If we assume that the background noise in such areas would normally be

46 dB(A) were the motorway not present, we can calculate the maximum distance at which the noise from the motorway would still be clearly distinguishable (say 10 dB(A) above the normal background noise level⁴) at 1.2m. above the ground using either of two equations depending upon the properties of the intervening terrain.

If the motorway is travelling over acoustically soft terrain e.g. open grassland, the maximum distance is defined by d in the following equation:

$$LB = LT - 10 \log\left(\frac{d'}{13.5}\right) + 5.2 \log\left(\frac{3h}{d + 3.5}\right) \quad (3.4)$$

where:

LB is the background noise level dB(A) + 10 dB(A)
 LT is the theoretical predicted noise level at 10m from the carriageway edge corrected for traffic speed and the percentage of heavy vehicles
 $d' = [(d + 3.5)^2 + (h - 0.5)^2]^{0.5}$
 d is the horizontal distance from the carriageway edge m.
 h is the vertical height above ground of the receiver m.

Over acoustically soft ground, the motorway noise would be theoretically distinguishable above the background noise at a maximum distance of 495 m.

If instead of soft terrain the motorway is passing over acoustically hard ground e.g. tarmacadam, water or frozen ground the equation for determining d is:

$$LB = LT - 10 \log\left(\frac{d'}{13.5}\right) \quad (3.5)$$

where:

LB is the background noise level dB(A) + 10 dB(A)
 LT is the theoretical predicted noise level at 10m from the carriageway edge corrected for traffic speed and the percentage of heavy vehicles in the traffic
 $d' = [(d + 3.5)^2 + (h - 0.5)^2]^{0.5}$

The theoretical maximum distance that the motorway noise is still dis-

⁴ A 10 dB(A) change in noise level corresponds subjectively to an approximate doubling or halving of loudness.

tinguishable above the background noise level when it is propagating over acoustically hard ground is approximately 6.5 km. However it is unlikely that in reality motorway noise would be noticeable at such a distance due to atmospheric absorption and meteorological effects.

A given sound power from road traffic noise (a line source) reducing approximately at 3 dB per doubling of distance will propagate further for identical conditions than a point source (e.g. industrial or construction noise) which falls off at least 6 dB(A) with each doubling of distance e.g. noise levels from a small industrial source producing 90 dB(A) at 10 m. (the legal limit in the United Kingdom) would not be noticeable above a background noise level of 46 dB(A) at a distance of approximately 2 km.

The results from these theoretical calculations indicate that where there is a major linear source of noise such as a busy motorway, noise levels will be noticeably higher at quite considerable distances (i.e. between 495 m. and 6,460 m.) depending upon the type of intervening terrain and assuming the absence of any screening effects and a point source will not be noticeable at approximately 2 km. These results indicate that the spatial scale for predicting noise levels in rural areas may need to be quite large to avoid noise levels from outside of the area significantly affecting noise levels inside the area. However, such a spatial unit would not be practical for urban areas as the resolution often required for describing noise levels in urban areas will be reflected by the underlying demographic characteristics. An average noise level predicted for an area of 6 km² would often include such a large variation in noise within the urban area it would have no practical value.

The 1 km² square, as marked on ordnance survey maps, is a practical unit to choose, as demographic data are often supplied for this spatial unit. It also provides a practical scale for the supply of noise information. Noise levels predicted on a one 1 km² square scale would provide a manageable amount of information without masking the general variation in pollution. The data would, also, be readily related to Ordnance Survey information.

Thus the one 1 km² square has been chosen as the spatial unit for the

proposed model despite the possible error in rural areas. The effects of external noise on internal noise levels for this spatial scale is discussed further in Section 6.5.

This discussion suggests that prediction model accuracy can be improved by:

1. selecting a number of area characteristics that discriminate highly between different environmental conditions,
2. developing an unambiguous method of model application for a suitable spatial scale and
3. using a model structure that allows for interdependency between the predictor variables.

3.2.2 Selection of Noise Predictor Variables

Wood's hypothesis (WOO 74):

'that environmental pollution is primarily related to the type and degree of human activity within an area',

suggests a basic causal relationship between pollution levels and demographic variables. This has influenced previous choices of predictor variables. It is hypothesised that land use and traffic have a causal relationship with noise levels and that this will form the basis for developing the noise prediction model

The particular measure of land use that is to be the predictor variable must be selected carefully so that it differentiates between the various levels of environmental pollution. However, this choice is limited by the land use data available.

Land use data are most commonly supplied for the following or similar categories:

1. Industrial.
2. Commercial.

3. Residential.
4. Open space.
5. Water.

Previous research has shown that traffic is an important source of noise in most urban areas. Pocock's (POC 79) suggests that road network density can be used as a traffic indicator, but it does not take into account traffic on through roads such as motorways. However, Pocock's models could only be used as a partial models for predicting national levels of ambient noise as they are specific to urban areas and possibly only one urban area. This research attempts to extend the scope of area-based prediction models to a national scale. The proposed model, therefore, requires a traffic indicator that is sensitive to a broader set of traffic conditions.

A more direct measure of traffic should ensure that the relative importance of through-roads is not overlooked and that any regional or seasonal variations in traffic flows are accounted for. Such a predictor variable should provide a means of predicting the varying noise during the day, week and year due to differences in traffic flows.

Most local authorities collect traffic data so that they are available for a single stretch of road as hourly vehicle counts, or as average hourly flows for a period of the day.

Given the limitations of the data, an appropriate measure of traffic is vehicle density (T) defined by :

$$T = \sum_{i=0}^n F_i l_i \quad (3.6)$$

Where : F is the hourly vehicle flow for the ith stretch of road, l is the length of road stretch i (km.), and n is the total number of road stretches in the 1 km² square.

This in fact represents the total number of vehicle kilometres per 1 km² per hour. Although complex in its calculation, such a measure of traffic flow would seem tolerably practical to many users especially those local authorities that store their traffic count and road link data on computer.

The model proposed here has, therefore, two predictor variables: land use and vehicle density. It is likely that these two variables are interdependent e.g. vehicles densities are often higher in industrial areas than in open spaces.

3.2.3 Noise Prediction Model Design

A prediction matrix is used to predict levels of noise pollution because a matrix structure allows for interactions between the land use and vehicle density variables in the two axes of the matrix.

The axes of the matrix are defined by the theoretical model predictor variables, land use and vehicle density and its dimensions are determined by the number of cells.

Each cell in the matrix is defined by a category of land use and a range of vehicle density.

For an urban model, Pocock (POC 83) compared two different methods of dividing the matrix axes into categories. His first model (POC 79) used nine land use categories and three network density categories. He found that noise levels varied more along the axis defined by road network density than along the axis defined by land use. Similar variances along the matrix axes were found when the number of land use classifications was reduced to four and the number of network density categories increased to five.

It is likely that any improved national model requires more than four land use categories to distinguish between noise levels, as there is a wider range in noise levels nationwide than found in a single urban area. On the other hand, the range of traffic conditions will not differ greatly from those found in the West Midland study. Thus the proposed model uses five vehicle density categories in accordance with Pocock's findings for network density.

3.2.4 Definition of Noise Model Land Use Categories

Most noise prediction models (BSI 67, PRI 72, ATT 76a, TMG 76 and PRA 78) have used qualitative criteria in assigning areas to a category. This can result in ambiguity and possibly in false assignments. Pocock (POC 79) clearly defines each of the area classifications by specifying percentages of

four basic land uses: open space, residential, commercial, and industrial within each 1 km² square. The use of such quantitative criteria for a specified spatial unit enables the model to be applied more systematically. Despite this improvement the choice and definition of each category is still somewhat arbitrary.

Given the apparent accuracy of Pocock's model (± 1.7 dB(A)) his land use categories form the basis of those chosen for the proposed model.

Eight land use categories are used:

1. Open space,
2. Residential,
3. Commercial,
4. Industrial,
5. Residential/Commercial,
6. Residential/Industrial,
7. Commercial/Industrial,
8. Residential/Commercial/Industrial.

Combinations of open space with other land uses are not given category status. With a few exceptions, such as rural motorways, open space is not a traffic generator. Open space is generally associated with a lower vehicle density and an attenuation of environmental noise with distance. It is assumed that the vehicle density predictor variable would provide enough differentiation between areas belonging to the same land use category but possessing significantly different amounts of open space. More emphasis is placed on the noise generating capacity of any 1 km² square. Thus the assumption should be valid in 1 km² squares where open space occupies less than 50% more land than the next most prevalent type of land use.

It is assumed that the land use categories chosen will be sufficient to distinguish between the range of noise climates found throughout the United

Kingdom. Each of the categories is defined by percentages of open space, residential, commercial, and industrial land use. As in previous models the choice of categories and their definitions are still somewhat arbitrary.

3.2.5 Specification of Noise Model Land Use Categories

Previous prediction methods have failed to specify ways in which individual land uses or activities may be assigned to particular land use categories. This can produce model error. For instance, a nursing home may imply either residential or commercial land use.

The proposed model classifies land use mainly by common sense with regard to their noise-producing potential. When detailed land use data are available these classifications are modified. Land uses that do not obviously fall into any one category, or that generate noise levels atypical of their normal group, are placed in the category which is most appropriate to their noise generating ability. For example: commercial warehouses are classified as industrial since they involve the loading and unloading of goods. This activity produces more noise, in general, than that produced by other commercial activities. Nursing homes are classified as residential as they generally produce less noise than most commercial activities. Appendix B lists the land uses included in each category.

Often land use is not supplied in sufficient detail for these considerations. This deficiency may result in an increase in model error.

Pocock (POC 79) found that, in general, a land use that occupied less than 5% of a 1 km² square does not significantly affect the average noise level within that area.

However, given the limited accuracy of the supplied land use data, 10% is the minimum reliable unit of land use, thus limiting the minimum percentage that can be confidently used to define the land use categories.

The proposed model includes residential, commercial and industrial land use categories. The 1 km² square is classified as residential, commercial or industrial if the land use occupies a percentage of land greater than or equal to 20%, 15%, and 10% respectively, provided that the land occupied by

another land use does not exceed it by 50% or more e.g. if residential land use occupies 21% of the area it is classified as residential but if commercial land occupies 71% of the same area it is classified as commercial. The 20%, 15%, and 10% figures, although somewhat arbitrary, are chosen to reflect the general trend in noise across the three categories. The noise generated by industry is generally greater than that generated by commercial and residential areas. Therefore industry will influence noise levels at a lower percentage than the other land use categories.

The individual land use categories are defined more specifically as:

Open space

Where residential land use is less than 20%, commercial land use is less than 15%, and industrial land use is less than 10%.

Residential

Where residential land use is greater than or equal to 20%, commercial land use is less than 15%, and industrial land use is less than 10%, or where residential land use occupies 50% or more of the 1 km² square than the next major land use (excluding open space).

Commercial

Where commercial land use is greater than or equal to 15%, residential land use is less than 20% and industrial land use is less than 10%, or where commercial land use occupies 50% or more of the 1 km² square than the next major land use (excluding open space).

Industrial

Where industrial land use is greater than or equal to 10%, residential land use is less than 20%, and commercial land use is less than 15%, or where industrial land use occupies 50% or more of the 1 km² square than the next major land use (excluding open space).

Residential/Commercial

Where residential land use is greater than or equal to 15%, commercial land use is greater than or equal to 15%, industrial land use is less than 10%, and where residential and commercial land uses do not exceed each other by 50% or more.

Residential/Industrial

Where residential land use is greater than or equal to 20%, industrial land use is greater than or equal to 10%, commercial land use is less than 15%, and where residential and industrial land uses do not exceed each other by 50% or more.

Commercial/Industrial

Where commercial land use is greater than or equal to 15%, industrial land use is greater than or equal to 10%, residential land use is less than 20%, and where commercial and industrial land uses do not exceed each other by 50% or more.

Residential/Commercial/Industrial

Where residential land use is greater than or equal to 20%, commercial land use is greater than or equal to 15%, industrial land use is greater than or equal to 10% and where residential, commercial and industrial land uses do not exceed one another by 50% or more.

3.2.6 Definition of Noise-model Vehicle Density Axis

The vehicle density categories selected cover the likely range of vehicle densities to be found throughout the United Kingdom. The maximum likely vehicle density is calculated as that which would occur at a busy motorway intersection in an urban area. Thus the range is assumed to be 0 to 8,000 vehicle kilometres per hour per 1 km² square.

The range is divided into the following five categories:

1. 0 to 500 vehicle km/hr/km²,
2. 501 to 1,000
3. 1,001 to 2,000
4. 2,001 to 4,000
5. 4,001 to 8,000

The ranges are chosen so that theoretically the range in noise levels within each vehicle density category is 3 dB(A) with the exception of the first category. Theoretically, a doubling of incoherent noise sources produces a 3 dB(A) increase in sound level. Theoretically the resulting model accuracy should be similar to that of Pocock's model (± 1.7 dB(A)). Model accuracy is discussed further on Page 105.

Figure 3.1 shows the prediction matrix as defined by the land use and vehicle density categories.

A total of forty categories are defined. The area-types defined may not all exist. Some may exist only at certain times of the day. For instance, it is unlikely that open spaces would have a vehicle density of above 4,000 veh. km/hr/km² and it is unlikely that a residential/commercial/industrial area would have a vehicle density of less than 500 veh. km/hr/km² during the daytime period.

3.3 Construction of Theoretical Prediction Model for Air Pollution

Unlike the noise model, the air pollutant prediction model is dependent upon data gathered independently from the research. As a consequence the prediction model design is severely restricted by the data available.

Land Use	Traffic Density (veh.km/hr/km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open Space					
Residential					
Commercial					
Industrial					
Residential/ Commercial					
Residential/ Industrial					
Commercial/ Industrial					
Residential/ Commercial/ Industrial					

Figure 3.1 The theoretical noise prediction matrix

3.3.1 Selection of a Spatial Scale for Air Pollution Prediction

Smoke and sulphur dioxide are both primary pollutants, i.e. pollutants emitted directly by the source, and are therefore likely to relate to the underlying demographic characteristics of an area.

Generally air pollution consists of an underlying pattern of local variations due to local small emissions (area sources) with a larger scale variation in levels superimposed which result from individual large emissions (point sources).

The policy in the United Kingdom of disposal through dilution and dispersion has resulted in the emission of large quantities of certain air pollutants in conditions where there is rapid dilution and dispersion i.e. by discharging the air pollutant from tall chimneys. These emissions can be distributed over a large area (SMI 75) especially if the air pollutant is a persistent species. Such pollutants may require a large spatial scale of prediction.

However, in average conditions it is estimated that these emitters produce maximum ground level concentrations at a distance down wind from the chimney of 10 to 15 times the chimney height (or the effective chimney height if due allowance is made for buoyancy of a hot plume) (WSL 72).

Usually smaller quantities of air pollution are discharged from short chimney stacks or at ground level and with reduced buoyancy. They rely on the air close to the ground to dilute the pollutants. Consequently this pollution remains fairly localised and accounts for a disproportionate part of the local ground level concentrations of the air pollution. It is these local ground level concentrations that are most likely to relate to the demographic characteristics of the area. Methods of prediction for pollution from these sources are comparable with those for noise pollution as only a relatively small spatial scale of prediction is required.

The Warren Spring Laboratory study of the effect of the local surroundings on smoke and sulphur dioxide concentrations in Greater London and Sheffield used land use classifications for an area of 1 km. radius around the

monitoring site (WSL 72). Other researchers have shown that this distance gives as good a correlation between sulphur dioxide emissions and concentrations as those for larger areas and better than those for smaller areas (MAR 67). Most industrial chimneys apart from those as tall as power station chimneys would in theory produce maximum ground level concentrations within this distance for average wind speeds.

Demographic data supplied by the Warren Spring Laboratory for each of their smoke and sulphur dioxide monitoring sites do not have a defined spatial scale but relate generally to the local surroundings.

No alternative demographic data were available in practical terms and thus the air pollution model is restricted to predicting local variations in air quality largely produced by the area sources.

It may be possible to reduce the error in the prediction model due to the influence of point sources by applying regional correction factors that would reflect these larger scale variations in air quality.

3.3.2 Selection of Predictors of Air Pollution

Local variations in air pollution are the result of the number and intensity of pollutant sources within the locality and their dispersion characteristics. It is hypothesised that the intensity and number of sources of smoke will depend upon the land usage and whether the area is subject to a smoke control order.

The Royal Commission on Environmental Pollution's Fifth Report (RCE 76) states that 'smoke control has had an overall effect of reducing emissions of sulphur dioxide as well as smoke'. This indicates that there may be a correlation between smoke control and sulphur dioxide emissions. Therefore it is hypothesised that sulphur dioxide concentrations will also depend upon the land usage and whether the area is subject to a smoke control order.

The type of land use will affect the number and strength of sources of smoke and sulphur dioxide e.g. they will normally be much lower in rural areas (WSL 72).

Levels of smoke maybe lower in smoke control areas due to different

fuel usage i.e. gas, electricity, anthracite, low volatile steam coals, coke and smokeless fuel instead of unauthorised 'smoky' fuels such as other coals, wood and oil⁵. The effect of smoke control on sulphur dioxide levels described by the Royal Commission on Environmental pollution may be due to many of the alternative sources of energy having smaller emissions of sulphur dioxide at low levels than those resulting from unauthorised fuels e.g. switching from either coal to gas or coal to electricity would reduce low level emissions of sulphur dioxide in the smoke control area.

The reduction of sulphur dioxide is not a stated aim of the smoke control provisions of the Clean Air Acts and high sulphur content is not specifically given as a reason for the government to refuse to authorise a fuel as smokeless. The Royal Commission Report states that, although in the early days of smoke control, fuels which were adequately smokeless were authorised without specific consideration of their sulphur content, since the late 1970s some fuels have been rejected because of their high sulphur content. Table 3.4 shows that on average smokeless fuels contained (and still do today) less sulphur by percentage weight than fuel oil and bitumen coal.

Sulphur dioxide emissions can be controlled using powers granted to the Secretary of State for the Environment under the 1974 Control of Pollution Act (BAL 83). Following requests from the Corporation of the City of London, special legislation was introduced in 1972 for the purpose of phasing in a 1% limit on the sulphur content of fuel oils throughout the City of London area (COL 71).

Between seventy-seven and eighty-nine percent of dark smoke in large urban areas has been attributed to traffic (BAL 77). Thus, the amount of traffic in an area and especially diesel traffic may be an important factor in the prediction of smoke levels.

The dispersion characteristics of the emissions of smoke or sulphur dioxide will depend upon the effective source height and the meteorological conditions e.g. wind direction and atmospheric stability.

⁵Unauthorised fuels may be used in smoke control areas if burnt on an exempted fireplace (or unless they can be burnt without smoke emission).

Meteorological conditions vary geographically. Figure 3.2 shows the Pasquill atmospheric stability categories over Great Britain which indicate the dispersion of air pollutants from the ground or from chimneys. The categories range from very unstable conditions (category A)⁶ through neutral conditions (category D)⁷ to very stable conditions (category G)⁸. The frequency of the different atmospheric stabilities will effect the measures of smoke and sulphur dioxide e.g. if stable conditions occur more than 2% of the time the 98th percentile value will be higher than in areas where the frequency is lower (assuming all else is equal). This indicates that prediction model may require some regional factor to take into consideration variations in meteorological conditions.

Other regional factors that may influence smoke and sulphur dioxide concentrations are:

- Distribution of the major smoke/sulphur dioxide emitting industries.
- Fuel usage and fuel characteristics.
- Population density (BEN 76).
- Housing density (MAR 67).

The distribution of the smoke and sulphur dioxide producing activities could be explained by using land use as a predictor. However, if a broad land use class is defined, e.g. Industry, it is assumed that all industries have similar source strengths and fuel use and hence that there is no geographical differences in emissions. It is well known that coal mining areas attract industries which are major emitters of smoke and sulphur dioxide, e.g. coal fired power stations and coal processing industries, these industries are more scarce in other parts of the United Kingdom.

⁶Occurs typically on a warm sunny summer afternoon with light winds and almost cloudless skies when there is strong solar heating of the ground and the air immediately above the surface.

⁷Occurs in cloudy conditions or when ever there is a strong surface wind to cause vigorous mechanical mixing of the lower atmosphere.

⁸Occurs typically on a cold clear calm night when there is strong cooling of the ground and of the lowest layers of the atmosphere which results in a strong inversion of temperature



Chart value	Percentage frequency of Pasquill stability:							Average wind at 10m (m/s)
	A	B	C	D	E	F	G	
80	0.0	4	11	80	3	2	0.0	7.2
75	0.2	4	13	75	4	4	0.5	6.5
70	0.3	4	14	70	5	5	0.7	5.7
65	0.5	5	15	65	7	6	1.0	5.0
60	0.6	6	17	60	7	8	1.4	4.4
55	0.8	7	19	55	7	10	1.7	4.0
50	1.0	9	21	50	8	10	2.0	3.5

Figure 3.2 Frequency of occurrence of the Pasquill stability categories over Great Britain.

Fuel usage (e.g. coal consumption) and the characteristics of the fuels burnt (e.g. sulphur content of coal) in the regions of the United Kingdom may also influence levels of smoke and sulphur dioxide (WSL 72 and WEA 75).

Figure 3.3 shows the relative emissions of sulphur dioxide in thousand tonnes per year within each 20 km² square covering the United Kingdom in 1970. The figure was derived by Smith and Jefferey (SMI 75) from data on:

- The consumption of primary fuels by all the major consumers (DOT 71)
- Maps showing the geographical distribution of the relevant major industries (MOH 68).
- The sulphur content of fuels used, and where appropriate, the retention of sulphur in the ash or, in the case of iron foundries, in the iron itself (WSL 72 and WEA 75).

It can be seen that both the London and South Wales regions which burn coals with low sulphur content, have high sulphur dioxide emission levels. This is due to the large quantities of coal burnt in these areas, sulphur dioxide from petrol refining in South Wales and oil-fired space heating in London's commercial buildings. Sulphur dioxide emissions from fuel oil are particularly important in London's central area (BAL 80).

No comprehensive study has been conducted on the total effects of these hypothetical regional factors on ambient air in the United Kingdom. They may have no net effect or they may be very significant.

The proposed air pollution prediction model has two predictor variables: land use and smoke/no smoke control. This simple model will be tested to determine whether there is a relationship between these variables and the proposed measures of smoke and sulphur dioxide. Simple regional classifications are also used to indicate whether there are any regional differences unexplained by these two variables. This is similar to the analysis used by Warren Spring Laboratory for certain areas (see Page 44).

It is unfortunate that due to the lack of appropriate data the monitoring site's local surroundings could not be classified according to its vehicle

density as this demographic variable may have important implications for smoke concentrations throughout the United Kingdom. Similarly it would also have been preferable to classify each of the areas in terms of coal consumption for predicting sulphur dioxide concentration.

3.3.3 Air Pollution Prediction Model Design

A matrix type model structure is also chosen for the air pollutant prediction model to allow for interactions between the predictor variables.

The matrix has two dimensions:

1. land use
2. smoke control

3.3.4 Definition of Air Pollution Model Land Use Categories

The choice of predictor variables for the air pollution model is restricted to land use categories based upon the Warren Spring Laboratory monitoring site classifications for land use and smoke/no smoke control.

The Warren Spring Laboratory use fourteen land use categories to describe the surroundings of their air pollution monitoring sites. The land use categories are:

- A1: Residential area with high-density housing (probably terraced) or with medium-density housing in multiple occupation, in either case surrounded by other built up areas.
- A2: Predominantly A1, but interspersed with some industrial undertakings.
- A3: Residential area with high-density housing or medium-density housing in multiple occupation surrounded by or interspersed with other areas with low potential air pollution output (parks, fields, coast).

- B1: Residential area with medium-density housing, typically an inner suburb or housing estate, surrounded by other built up areas.
- B2: Predominantly B1, but interspersed with some industrial undertakings.
- B3: Residential area with medium-density housing surrounded by or interspersed with areas with low potential air pollution output (parks, fields, coast), or any residential area with low-density housing.
- C1: Industrial area without domestic premises.
- C2: Industrial area interspersed with domestic premises of high density or in multiple occupation.
- D1: Commercial area or one with predominantly central heating.
- D2: Town centre with limited commercial area, possibly mixed with older residential housing and/or minor industry.
- R: Rural community.
- O1: Open country but not entirely without source(s) of pollution, e.g. airfields.
- O2: Completely open country: no sources within at least $\frac{1}{4}$ mile.
- X: Unclassified site, or mixed area.

These categories form the basis for the selection of the land use predictor categories.

Eight theoretical land use categories are chosen as predictors of smoke and sulphur dioxide

1. Open space
2. Residential
3. Commercial

4. Industrial
5. Residential/Commercial
6. Residential/Industrial
7. Commercial/Industrial
8. Residential/Commercial/Industrial.

Where possible these categories are calibrated using the Warren Spring Laboratory data. The Warren Spring Laboratory land use classifications are grouped together to form six of the eight theoretical predictor categories as shown in Table 3.5.

3.3.5 The Theoretical Air Pollution Prediction Model

The eight land use categories are combined with the two variables which identify whether the monitoring site is within a smoke control area. The resultant two dimensional prediction model is shown in Figure 3.4.

3.4 Validation of the Theoretical Models

3.4.1 Partial Testing of the Noise Prediction Model

The research hypotheses are partially tested along two axes of the matrix. Where possible, the twelve matrix cells defined by the residential land use axis and the 2,001 to 4,000 veh. km/hr/km² vehicle density axis are calibrated for noise. This allows the variations in noise levels to be tested across the land use and vehicle density categories.

The residential land use category is chosen as one axis since it is one of the land uses most sensitive to noise and therefore of great interest to planners. It is also an abundant land use category with a wide range of vehicle densities. It is, therefore, an appropriate category to test the variation in noise levels across the vehicle density categories. The 2,001 to 4,000 veh. km/hr/km² vehicle density category is used to test the variation in noise

Predictor category	Warren Spring classification
Open space	R, O1, and O2.
Residential	A1, A3, B1 and B3.
Commercial	D1
Industrial	C1
Residential/ Commercial	No data
Residential/ Industrial	A2, B2, and C2.
Commercial/ Industrial	No data
Residential/ Commercial/ Industrial	D2 and X.

Table 3.5 Partial calibration of the air prediction model's land use categories

	Smoke Control	No Smoke Control
Open space		
Residential		
Commercial		
Industrial		
Residential/ Commercial		
Residential/ Industrial		
Commercial/ Industrial		
Residential/ Commercial/ Industrial		

Figure 3.4 Theoretical air pollution prediction matrix

across the land use categories. It is the vehicle density category that is most likely to be found in all land use types during the daytime period when a noise survey is most practical.

Selection of Noise Survey Time Period

To allow the calibration of the two matrix axes, measurements must be taken during a period of the day that has fairly constant noise levels. A reasonably long period of time is required to maximise the number of noise measurements that can be taken.

Attenborough *et al.* (ATT 76a) found that background noise levels are fairly constant on weekdays between 9am. and 4pm. with only a slight increase in noise levels between noon and 2pm. Utley (UTL 82) found that at two measurement sites levels of L_{A10} and L_{A90} did not vary during this period by more than 10 dB(A) and 4 dB(A) respectively. This compares with variations in L_{A10} and L_{A90} noise levels of 25 dB(A) and 27 dB(A) throughout the 24 hour day Monday to Friday.

A fairly constant vehicle density is also required so that the calculated average hourly vehicle density is representative of traffic conditions throughout the noise survey period. Weekday traffic levels are fairly constant between 10am and 4pm. Figures 3.5 and 3.6 shows the hourly changes of traffic flow for three types of road within the United Kingdom.

This suggests that the matrix should be partially calibrated using noise measurements gathered between 10am. and 4pm.

The spring and summer seasons are chosen for conducting the noise survey because the weather conditions during these periods are more likely to be dry and calm and therefore provide maximum opportunity for the collection of survey data. There maybe some seasonal variations in traffic flows as indicated in Figures 3.5 and 3.6. Seasonal variations in noise levels are discussed further in Section 4.6.1. The exact seasonal periods used for collecting the noise survey are given in Section 5.1.1 and shown in Figure 5.1

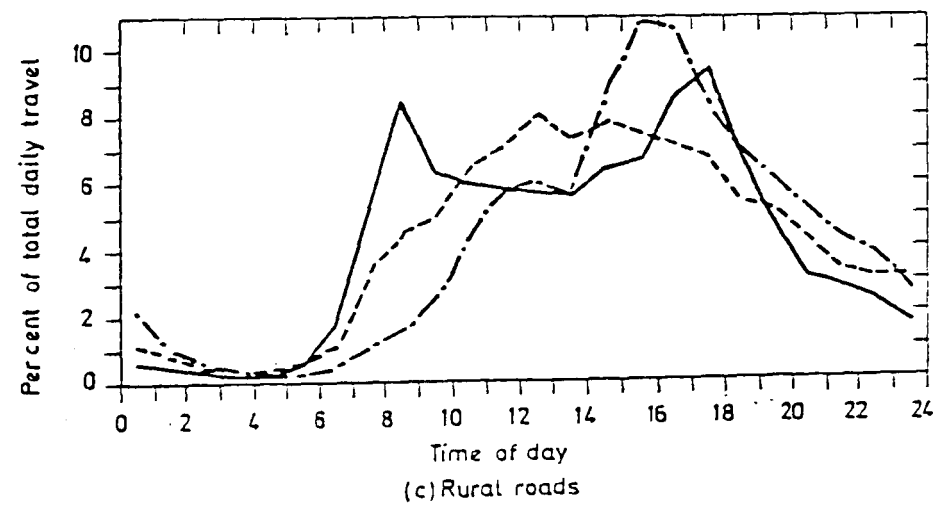
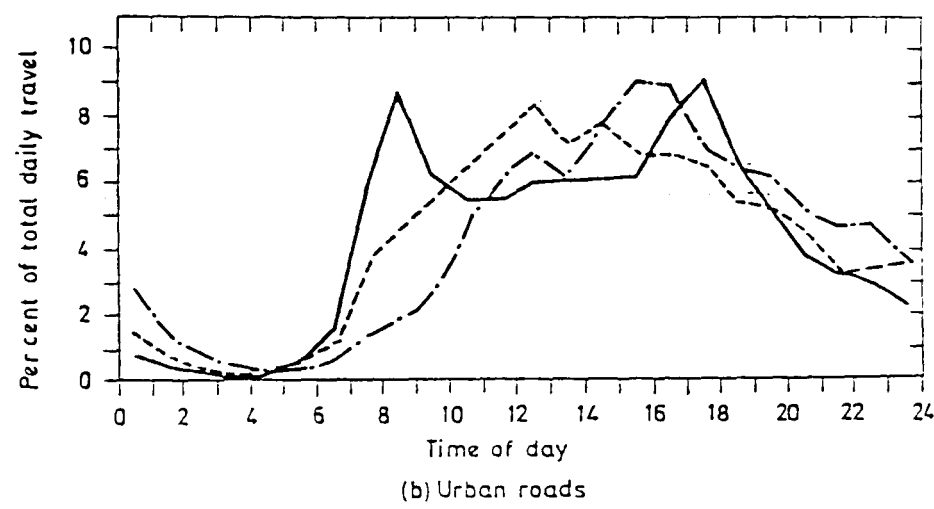
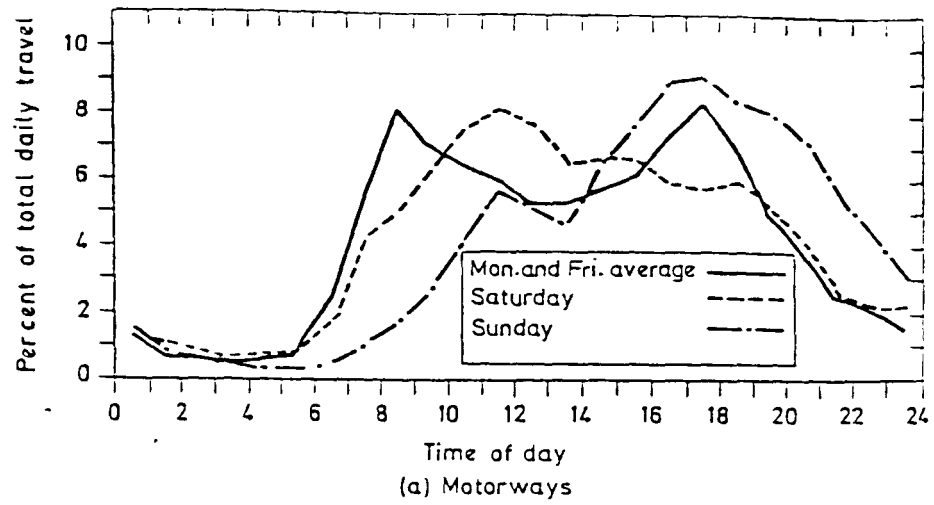
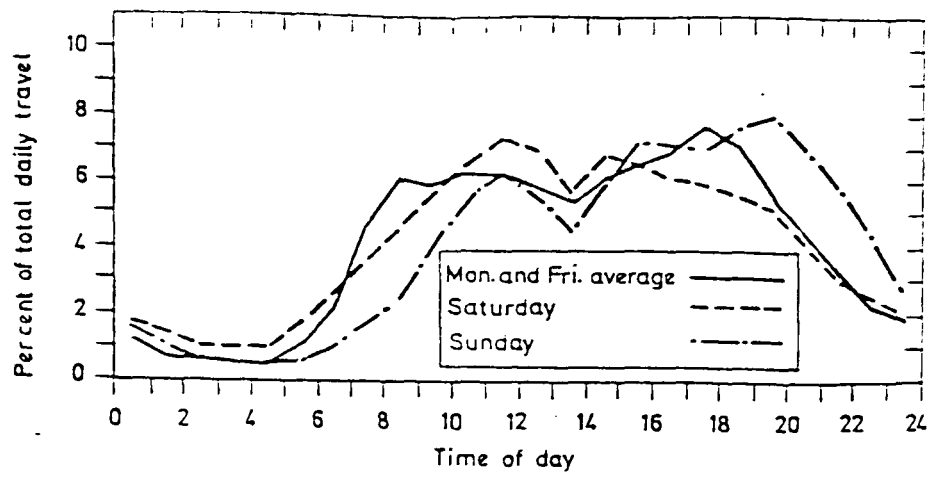
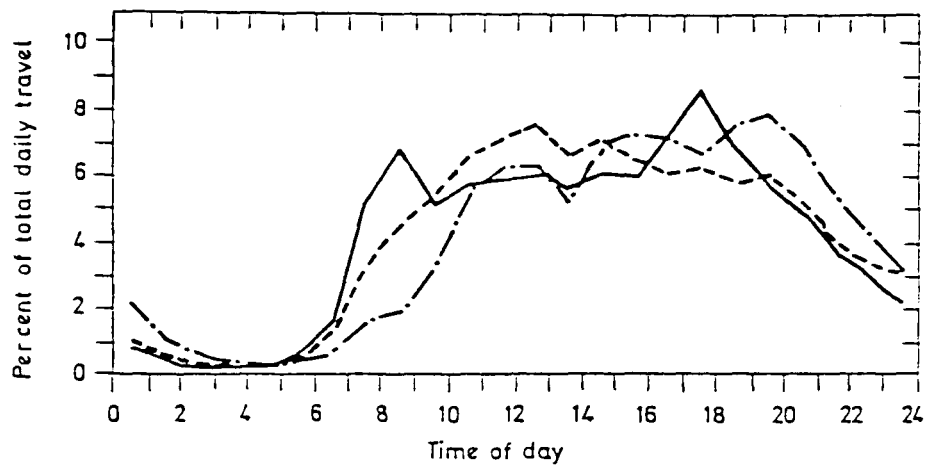


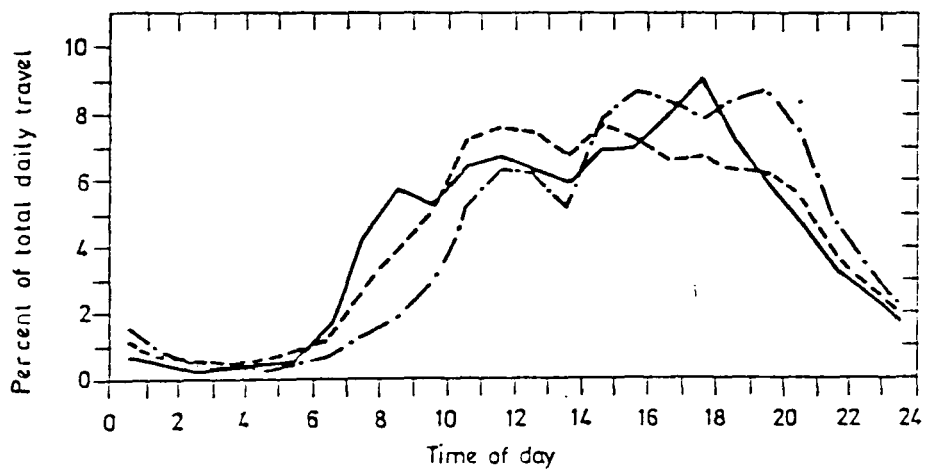
Figure 3.5 Daily traffic patterns in the U.K. February (DUN 69)



(a) Motorways



(b) Urban roads



(c) Rural roads

Figure 3.6 Daily traffic patterns in the U.K. August (DUN 69)

Selection of Case Study Areas

Attenborough *et al.* (ATT 76a) found that there were regional variations in background noise levels that could not be explained by the prediction model. The proposed research explores the possibility that there are regional variations in noise levels that cannot be explained by the demographic variables chosen (see Section 6.3).

This hypothesis is tested by selecting case study areas from three different regions. Each of the regions have certain characteristics that could produce a significant difference in noise levels. The case study areas will test whether the proposed model is robust when predicting noise levels in different regions.

In addition, case study areas should include those area-types specified by the two matrix axes to be calibrated. Recent land use and traffic flow data are needed for each area. The practicalities of noise surveillance need also to be considered.

The three case study areas were selected since they fulfil the above criteria:

1. The Borough of Milton Keynes,
2. The London Borough of Bexley,
3. The West Midlands Metropolitan County.

Each case study areas includes large residential developments and together they provide a wide range of commercial and industrial land uses. The density of residential land use and traffic varies between each region. In general the Borough of Milton Keynes has lower housing and traffic densities than the more urban West Midlands and London Borough of Bexley areas. Residential areas in the City of Milton Keynes are often screened from busy roads by earth banks. Land use is segregated in the City of Milton Keynes whereas it is intermixed in the other two case study areas especially in the West Midlands. Industry in the West Midlands is 'heavier' than in the Borough of Milton Keynes and Bexley. Traffic in the West Midlands tends to

contain more heavy goods vehicles. The West Midlands contains large areas of derelict land.

The regional differences between the case study areas may not be typical of the regional differences found nationwide. The student data are used to test for regional differences throughout the United Kingdom although these data are less rigorous than those obtained from the three case study areas. For this purpose the United Kingdom was divided into the regions shown in Figure 3.7.

3.4.2 Partial Testing of Air Pollution Model

The Warren Spring Laboratory monitoring site classification system can not be used to calibrate the commercial/industrial or residential/commercial land use axes of the theoretical prediction matrix (Figure 3.4). Other area-types are unlikely to exist e.g. open space areas which are subject to smoke control orders. These cells of the matrix cannot be calibrated using the Warren Spring Laboratory data and are therefore not tested. The extent to which the rest of the theoretical prediction matrix is tested depends upon the number of valid measures available for the other area-type categories. A breakdown of the number of measurements in each of the area-type categories defined by the theoretical prediction matrix is given in Appendix C.

Data Selection Criteria

Air pollution data for the year April 1980 to March 1981 was used to calibrate the prediction model.

In selecting valid measures of smoke and sulphur dioxide concentrations it is important to consider the number of daily readings used to derive the measurement statistic. An incomplete data set will introduce an error into the calculated statistical measures of long term smoke and sulphur dioxide pollution. This error will increase with decreasing sampling frequency.

The number of days between measurements is also important as smoke and sulphur dioxide exhibit seasonal variations (WSL 72).



Figure 3.7 Regional divisions used in the analysis of the student noise data and the Warren Spring Laboratory air pollution data.

The World Health Organisation (WHO 80) recommends that an air pollution data set is adequately balanced if each calendar quarter contains at least twenty percent of the total observations.

As stated in Appendix C, Warren Spring Laboratory summarise data for all measurement sites where the number of daily measurements taken throughout the year exceed ten. Clearly this selection criterion is not sufficiently stringent for the research purposes.

The year 1980 is defined by the Warren Spring Laboratory as a 364 day period with a winter period of 182 days. The World Health Organisation selection criterion was applied to these data. The worst case situation was considered i.e. when all of the missing data coincided in one calendar quarter. Thus, winter period variables were considered valid if more than 145 daily measurements were used in their calculation. Yearly variables were considered valid if more than 291 daily measurements were used.

Number of Sites Required to Represent Each Area-type

A minimum number of five sites is required to represent each area-type in the subsequent statistical analysis. This number of measurement sites represent a sufficient cross section for the calibration of each of the area-types defined by the prediction matrix and a sufficient number of degrees of freedom (4) to allow for the statistical analysis outlined in Chapter 7. A larger sample would possibly have been more representative.

3.4.3 Selection of Regional Areas

As discussed in Section 3.3.2, there are a number of regional factors that may influence the concentrations of smoke or sulphur dioxide. Little quantitative work has been done to determine whether these factors have important regional effects on ambient air quality or on how these factors interact. As a result the study of regional differences in air pollution is limited to a simple classification of the monitoring sites into ten regional groups.

The groups are based on the standard statistical regions within the United Kingdom. However, some modifications have been made as the num-

ber of standard statistical regions are too numerous for the size of the data set. The Northern region is divided between the North West, and Yorkshire and Humberside regions. Cumbria is classified as North West whilst the other Northern region counties are classified along with Yorkshire and Humberside as the North East region. The West Midlands and East Midlands regions are combined to form the Midlands region. The resulting ten regions coincide with those selected for the noise prediction study and are shown in Figure 3.7.

The selection of regions is not ideal as the boundaries chosen are not based on any hypothesised causal relationship between regional factors and air pollutants but relate to administrative boundaries.

Future researchers may improve upon this selection by performing a cluster analysis of the residuals from the two way analysis of variance (land use and smoke control), presented in Section 7.2, to determine whether there is any marked spatial pattern in the clusters of alike groups.

3.5 Resulting Hypotheses

The experimental design described in this chapter articulates the research hypotheses in a testable form. Three fundamental hypotheses have been identified that apply to both air and noise pollution prediction. A further two hypotheses are tested for noise pollution alone.

3.5.1 General Hypotheses

General Hypothesis One

‘That variations in the noise indices and the measures of smoke and sulphur dioxide are significantly correlated with variations in demographic area-type classification.’

This research tests whether L_{Aeq} , L_{A10} and L_{A90} are significantly correlated with the demographic variables land use and vehicle density. The relationships between the measures of smoke and sulphur dioxide with land

use and smoke control are also tested. The relationships between the demographic variables and levels of air and noise pollution are then used to develop national models for predicting noise levels and air pollutant concentrations.

General Hypothesis Two

'That there may be regional variations in noise and air pollutant levels not accounted for in the area-type classifications used in the proposed models.'

Measurements of L_{Aeq} , L_{A10} and L_{A90} taken in three case study areas, each in a different region of the country, will be examined for any regional variation unaccounted for by the demographic variables land use and vehicle density.

Regional variations are further tested using the less rigorous data obtained from Open University students living throughout the United Kingdom.

Should a regional differences in noise levels be identified, the following regional characteristics should be investigated, where feasible, as possible causes: percentage of heavy goods vehicles in traffic, vehicle speed, type of industry, degree of land use segregation, noise abatement measures and housing density.

Measurements of smoke and sulphur dioxide provided by the national survey of air pollution 1980-81 will be used to test for regional variations in air pollution that are unaccounted for by the predictors land use and smoke control.

If regional differences in air pollution levels are found, the following regional characteristics should be investigated, where feasible, as possible causes: meteorology, point sources, distribution of the relevant industries, fuel usage, and fuel characteristics.

General Hypothesis Three

‘That there is a relationship between different noise indices and between different measures of air pollution and that those relationships will vary according to the area classification.’

This hypothesis will be tested by comparing the values of noise indices L_{Aeq} , L_{A10} , L_{A90} , and $L_{A10}-L_{A90}$ in each area-type classification and each region of the United Kingdom. The variable $\frac{Smoke}{SO_2}$, where smoke and sulphur dioxide are both winter median daily values (October to March), is used to test whether there is a significant difference in the relative contributions of sources of smoke and sulphur dioxide in the different area-types and in different regions of the United Kingdom.

3.5.2 Noise Hypotheses

Noise Hypothesis One

‘That average noise levels within a 1 km² square are not significantly affected by noise produced by sources outside the 1 km² square.’

Areas that have an atypical noise climate for their area-type will be examined to determine whether this is due to the influence of external sources. This will be achieved by:

- examining those 1 km² squares where noise from ‘external’ sources are distinguishable above the ambient environmental noise.
- examining those 1 km² squares where the error of prediction exceeds the theoretical standard error.

Noise Hypothesis Two

‘That vehicle density (veh. km/hr/km²) is a better predictor than network density when either is used in conjunction with land use classifications.’

Each of the 1 km² square used to calibrate the prediction matrix will be characterised according to its network density as defined by Pocock (POC 79). A prediction model will be developed using this variable along with land use classifications and compared with the model proposed in this research.

Chapter 4

Design of Field Measurements

4.1 Introduction

This chapter outlines the objectives for the noise survey, the pilot noise survey and the subsequent objectives and methodology of the main noise survey in three case study areas.

4.2 Noise Survey Objectives

The noise survey objectives are to gather accurate measurements of ambient environmental noise levels so that those measurements can be used to:

1. test the research hypotheses described in Section 3.5.2 for the noise prediction model.
2. partially calibrate a model comprising of a matrix of predictor variables for the weekday period 10am. to 4pm.

The results obtained are used to develop the proposed models for predicting ambient outdoor noise pollution.

4.3 Collection of Demographic Data

The demographic data used to classify the 1 km² squares in each of the case study areas were supplied by regional and local governments. These raw

data are modified so that they are compatible with the proposed models specifications. The modifications are described in Appendix B.

4.3.1 Land Use Data

Borough of Milton Keynes land use data

Land use data for the city of Milton Keynes are available in the form of a 1985 1:10,000 map. Seven land use categories are represented on the map:

1. Residential
2. Main employment areas
3. Education
4. Centres (Commercial)
5. Health
6. Open space and Recreation
7. Vacant Land

The main employment areas include both commercial and industrial land.

The Milton Keynes Development Corporation also supplies company listings for each of the main employment areas along with a map of their locations.

Elsewhere in the Borough of Milton Keynes (BMK) land use data are only available for a limited number of towns and villages. Village and town planning reports (1976 to 1983) include 1:1,1250 maps classifying land use into the following categories, where they occur:

1. Housing
2. Shopping and Commercial
3. Recreation/Open space

4. Industry
5. Education and Social facilities
6. Allotments
7. Playing Fields
8. Churches and Graveyards
9. Vacant and Industrial Land

London Borough of Bexley Land Use Data

Very comprehensive numerical land use data were supplied by the Greater London Council (GLC) for each 1 km² square in the London Borough of Bexley (LBB) (see Appendix B). The data were gathered during a survey conducted in 1971 which was similar to the GLC survey reported by Gebrett (GEB 72). A series of corrections for updating the data to the year 1981 were also supplied. The corrections are based on planning applications granted between 1971 and 1981 and are less detailed than the 1971 land use survey data.

West Midlands Metropolitan County Land Use Data

A land use map of the West Midlands Metropolitan County (WMMC) was supplied by Midland Environment Ltd. The map displays numerical data of the percentages of land found in each of the 1 km² squares for the following land use categories:

1. Residential
2. Commercial
3. Industrial
4. Recreation
5. Vacant/Derelict

6. Agriculture

The map also displays a numerical representation of road network density as defined by Pocock (POC 79) and detailed in Section 2.2.1.

The map is compiled from a 1979 land use map made by the West Midlands Metropolitan County's Strategic Planning Division. Each of the above land use categories was outlined on a base map with a one 1 km² square Ordnance Survey based grid mapping overlay. A ten by ten subsidiary grid was then superimposed onto the cross-sections of the 1km grid of the mapping overlay. The percentage of land in each of these grid squares was then visually estimated and summed to produce percentages of land within each 1 km² square and used to compile the map supplied.

4.3.2 Vehicle Flow Data

Vehicle counts were only available for selected sites and roads within each of the case study areas.

Borough of Milton Keynes Vehicle Flow Data

Milton Keynes Development Corporation only has data for roads within the city of Milton Keynes. Automatic vehicle counts, based on the number of axles passing over a sensor are stored on computer. The vehicle flow is assumed to be half the number of axles counted. The sites are virtually all situated on the main 'grid' roads linking the different estate areas. There are very few counting sites on minor roads within the estates. Those minor roads that have been selected by Milton Keynes Development Corporation are said to have vehicle flows that are representative of roads within the estates (WEE 85).

Traffic flows at each site are counted twice yearly and supplied as computer listings of sites marked and numbered on a map of the area.

The Buckinghamshire County Council County Engineer's Department supply manually obtained turning counts for sites throughout the Borough of Milton Keynes. The vehicle flow data are available for consultation in the

County Engineer's department's office as printed count summaries.

London Borough of Bexley Vehicle Flow Data

Comprehensive traffic link data were available from the GLC for most of the major roads within London Borough of Bexley. The most recent traffic link studies in the Borough are winter 1985 and winter 1983. One less link is counted in the 1985 study. Both studies list data for the weekday period 10am. to 4pm.

Automatic and manual vehicle counts for minor roads within the Borough are available for consultation in the London Borough of Bexley council offices as traffic flow summary sheets.

West Midlands Metropolitan County Vehicle Flow Data

Traffic link data were also available from the West Midlands Metropolitan County. The data are presented in stylised map form for most of the major roads within the conurbation. 1985 traffic counts are displayed for the weekday period 7am. to 9pm.

Individual boroughs within the West Midlands Metropolitan County have data for the minor roads. These were not collected as the task would have been huge and would have produced only a small reduction in the error of calculating the 1 km² square's vehicle densities.

4.4 Characterisation of Grid Squares

Transcription errors, and changes in land use since the map data were compiled, make it necessary to consider what is the tolerable level of error in the land use data before there is likely to be a significant discrepancy in the prediction model.

4.4.1 Tolerable Error

Pocock (POC 79) suggests that generally any land usage below 5% of a one 1 km² square is unlikely to significantly affect noise levels within that 1 km²

square.

If we consider the total sound power of sources within and assume a uniform distribution of sources and source strengths over that area we can determine the theoretically permissible error in the area of land use relating to noise production that would give a predicted change in sound pressure level of ± 1.7 dB(A) which is the target accuracy of our model. Consider instead the change in source strength required to produce a change in sound power level of 1.7 dB(A). Using the equation for sound power level (SWL):

$$SWL = 10 \log\left(\frac{W_{ave.}}{W_o}\right) \quad (4.1)$$

Where:

$W_{ave.}$ is the average sound power in watts from the area's sources

W_o is the reference sound power

If the increase in sound power level is 1.7 dB(A) we can calculate the following:

$$\begin{aligned} 1.7 &= 10 \log\left(\frac{W_{ave.}}{W_o}\right) \\ 1.45 &= \left(\frac{W_{ave.}}{W_o}\right) \end{aligned}$$

If $W_{ave.}$ and W_o are equal their ratio is 1.0. An increase in the sound power level of 1.7 dB(A) produces a 45% increase in this ratio. W_o is the reference sound power and therefore constant. Thus we can conclude that an increase in noise level of 1.7 dB(A) would be produced by a 45% change in the sound power output from a given source. This means that, in terms of land use area percentages; a $\pm 45\%$ change in the area of the land use relating to noise would theoretically produce a change in noise levels of ± 1.7 dB(A))

If the noise producing percentage of a 1 km² square is only 20% then a 45% error in this 20%, i.e. 9% of the 1 km² square, will produce an error of ± 1.7 dB(A).

Industry and traffic generally produce the most noise. Thus the likely maximum tolerable error will especially apply to industrial land use and traffic density.

4.4.2 Land Use Characterisation

The matrix modelling approach rests on the need to define the range of land use percentages into discrete categories, thus delineating the 'cells' in the matrix.

The classification of the 1 km² squares in each case study area into their land use category is determined by the percentages of land use in the four basic land use categories defined in Section 3.2.4.

The Borough of Milton Keynes

The Milton Keynes Development Corporation city land use map and the borough planning reports are used to determine these percentages in the Borough of Milton Keynes. A 1 km² square grid is transcribed onto the Milton Keynes Development Corporation map from the Ordnance Survey maps.

Elsewhere land use maps are drawn from the town and village planning reports. These maps are compiled by re-classifying the land use categories defined in the report into the four basic land use categories. These four basic land uses are drawn onto 1:2,500 Ordnance Survey maps of the area.

The percentage of each land use in the 1 km² square is determined by visual assessment. A ten by ten grid overlay aided this assessment. Each grid square is defined by its dominant land use and the total percentage of each land use within the 1 km² square is the sum of the individual grid squares in each category.

Local knowledge and the Milton Keynes Development Corporation industry and business listings are used to distinguish between the industrial and commercial land use in each of the main employment areas displayed on the Milton Keynes Development Corporation city land use map.

London Borough of Bexley

The Greater London Council's land use data are used to determine the percentages of the four basic land use categories in each of the 1 km² square

overlapping with or within the London Borough of Bexley's boundary.

Land use data were supplied separately for each borough. To complete the land use classification of a 1 km² square that overlaps with an adjacent borough, i.e. Greenwich or Bromley, land use data from the adjacent borough are added to the Bexley data.

Both the Greenwich and Bromley data are supplied in acres and thus these data were converted to hectares to be compatible with the Bexley data.

The land use data supplied for those 1 km² square overlapping with the Greater London boundary with Kent were incomplete. The land use classification of these 1 km² square is completed using local knowledge and information shown on 1:10,000 Ordnance Survey maps.

The very detailed land use data, supplied by the Greater London Council, are reclassified into the four basic land use categories as described in Appendix B. The correction factors are added to these reclassified categories to update the data to 1981.

West Midlands Metropolitan County

The percentages of land use displayed on the map supplied by Midland Environment Ltd. are used to characterise the land use of each of the 1 km² square in the West Midlands Metropolitan County.

These data are converted into list form with the land use categories: Recreation, Vacant/Derelict, and Agriculture combined into the single basic land use category Open Space.

The network density variable displayed on the map for each 1 km² square is also listed and compared with traffic density as a variable for predicting ambient environmental noise.

4.4.3 Sources of Error in Land Use Characterisation

Errors in the classification of a 1 km² square in terms of land use would occur in the following circumstances:

1. where there has been a significant change in the area's land use since the gathering of the land use data,
2. if the land use data supplied use a different definitions of the four land use categories to those used in the proposed model,
3. if the land use data supplied are inaccurate and
4. where there is error in the processing of the data and classification method.

Every endeavor is made to eliminate these sources of error by:

- visually checking the land use data supplied whilst conducting the main noise survey and using local knowledge of land usage,
- selecting the most reliable sources of land use available and
- taking care in and checking the data processing.

Very few significant changes in land use were found. One 1 km² square in Milton Keynes appeared, from the land use map, to be Residential and another appeared to be Open space. However, both 1 km² square were dominated by construction sites and were reclassified into the industrial category.

4.4.4 Vehicle Density Characterisation

The vehicle density classification of each of the case study areas is determined by the ranges of vehicle densities defined in Section 3.2.6.

The length of each road stretch is measured from a 1:10,000 scale Ordnance Survey map using a mapping wheel. The accuracy of this measurement method is uncertain but is not expected to be a source of significant error.

The road stretch length is multiplied by the average hourly vehicle flow (weekdays 10am. to 4pm.) for that stretch. The West Midlands Metropolitan County traffic counts were supplied for the weekday period 7am. to 9pm.

These counts are corrected, using a correction factor supplied by the West Midlands Data Unit, so that they approximate to the weekday 10am. to 4pm. vehicle flow.

Actual vehicle counts are not available for all road stretches. In such cases estimates of the average hourly vehicle flow are used instead.

Vehicle flow estimates supplied by the local and regional authorities are used where they are available. Elsewhere one of two methods of estimation are used:

1. existing traffic counts are used to represent the vehicle flow in an adjacent road section where the change in flow between sections is known to be negligible and
2. typical average hourly vehicle flows are calculated for each classification of road. These figures are calculated by averaging the mean hourly vehicle counts (weekdays 10am. to 4pm.) for each road type.

It is likely that the typical flow for a particular road type will vary between the case study areas as do the road type classifications. Thus, typical hourly vehicle flows are determined separately for each case study area.

Typical average hourly vehicle flows were supplied by the local and regional authorities or calculated using the vehicle count data they supplied.

Table 4.1 gives the typical average hourly estimates of flow for each road type in each of the case study areas.

Local knowledge is used to distinguish between the residential road type categories.

The road type classification of roads in each of the 1 km² square surveyed is checked visually whilst conducting the noise survey. Roads with a vehicle flow atypical of their classification, or assigned group, are reclassified and the estimated flow adjusted accordingly. None of these alterations resulted in the vehicle density classification of a 1 km² square being changed.

Only post 1980 vehicle counts are used. This reduces the possible error in calculating the vehicle density due to significant changes in vehicle

Table 4.1 Typical hourly vehicle flows (weekdays 10am. to 4pm.) for each road classification in each of the case study areas.

ROAD CLASSIFICATION	BMK	LBB	WMMC
Primary	1030	-	1120
Principal	-	600	600
Residential (Busy)	220	190	150
Residential (Moderate)	100	100	100
Residential (Quiet)	37	44	40
Local Access Road	220	350	350
Other Unclassified	-	138	80

flow patterns inside the 1 km² square. Vehicle counts are not used if there has been a significant change in an area's vehicle flows since 1980, e.g. the opening of a by-pass or the pedestrianisation of areas.

All data are corrected to the year 1985 to eliminate error due to the general upward trend of vehicle flows from year to year (DOE 75). The correction factors used are 3% per annum for Borough of Milton Keynes, and 1% for the London Borough of Bexley area. No correction factor is required for the West Midlands Metropolitan County data as all the data supplied are for 1985.

The Borough of Milton Keynes correction factor was supplied by Buckinghamshire County Councils County Engineers Dept. The London Borough of Bexley correction factor is derived from Greater London Council traffic statistics for Outer London and Bexley.

Sources of Error in Traffic Density Characterisation

There is the possibility of a 1 km² square being wrongly classified in terms of its vehicle density where the following occur:

1. there is a significant change in the area's vehicle flow rates since the data have been gathered.

2. the road network has changed since the Ordnance Survey maps were published.
3. the traffic counts supplied are inaccurate or they are incorrectly copied.
4. the traffic counted by automatic sensors contains a large proportion of vehicles with more than two axles
5. the measurement of road lengths are inaccurate.
6. there is an error in the calculation of the vehicle density.

These sources of error have been largely eliminated by:

- using vehicle counts taken after 1980, and excluding any of these counts taken before any significant change in the vehicle flows within an area,
- correcting all traffic counts to be compatible with 1985 flows using regional annual changes in vehicle flows as correction factors where necessary,
- making a brief visual check of the traffic flows and road layout in each 1 km² square whilst carrying out the noise survey. Adjusting the vehicle density where there is an observed difference and
- carefully calculating the vehicle density figure.

4.5 Sample Area Selection

4.5.1 Grouping of Sample Squares into Cells of the Matrix

To test and calibrate the prediction method in two dimensions it was necessary to select 1 km² squares belonging to 'cells' within these two matrix axes. The two dimensions are defined by the '2,001 to 4,000 vehicle density' category row and the 'residential land use' category column within the prediction matrix.

Each 1 km² square in the case study areas is characterised according to its land use and vehicle density and assigned to its appropriate cell in the prediction matrix.

The two matrix axes chosen to partially calibrate the prediction matrix contain eleven matrix cells. If all area-types exist this produces eleven '1 km² square' subsets.

1 km² squares are, then, selected from these subsets for noise surveillance and the results are used subsequently to calibrate the prediction model.

However, a few of the area-types defined by these matrix cells may not be represented by 1 km² squares within the case study areas and therefore the number of '1 km² square' subsets that can be calibrated may be less than eleven.

4.5.2 Number of Sample Squares Required to Calibrate Each of the Area-type Categories

A minimum of three 1 km² squares are selected and used to calibrate each of the matrix cells. This gives data with more than one degree of freedom and allows for two independent tests of the variance within the matrix cell. This should enable a representative value of the typical ambient environmental noise to be obtained for each area-type classification.

Wherever possible, five 1 km² squares are used to calibrate the individual matrix cells. This reduces the influence that 1 km² squares, with atypical noise levels, have on the average noise level calculated for the matrix cell.

If all of the eleven cells in the two dimensions of the prediction matrix were fully populated, it would have been necessary to survey a total of sixty-five 1 km² squares.

4.5.3 Required Distribution of Selected Sample Squares, Within Each Matrix Cell, Across the Case-study Areas

An approximately equal number of 1 km² squares are chosen and surveyed from each of the case study areas. This allows testing of the hypothesis, that:

‘there are regional variations in noise levels unaccounted for by the prediction method’ using analysis of variance and multiple regression statistical techniques.

Wherever the range of demographic characteristics in the case study areas allowed, the 1 km² square areas were sampled in different parts of the case study area to prevent any bias which might occur by sampling adjacent 1 km² squares. However, this was not always possible as indicated in Figures 5.2 and 5.3.

4.6 Noise Survey Methodology

The partial calibration of the prediction matrix involves the measurement of the 1 km² squares selected according to the method outlined above.

A sampling technique is required for selecting noise monitoring sites, within each 1 km² square, that enables the survey to be performed within the operational and theoretical constraints of the research.

The noise survey methodology described below was designed prior to the publication of the International Standard ISO 1996-2 1987(E). However, the noise survey methodology fulfills the recommended measurement and reporting procedures described in this standard.

Theoretical Criteria

- The survey method should obtain accurate values of the noise indices L_{Aeq} , L_{A10} and L_{A90} typical of each 1 km² square.
- Sufficient data should be gathered in an appropriate manner to enable the research hypotheses to be tested.

Operational Criteria

- The noise survey design must consider the time constraints imposed by the length of the doctoral project and the limited meteorological conditions under which noise surveillance is feasible.

These demands and constraints are met by:

- restricting the survey season,
- taking measurements for a limited daytime period and
- using a spatial sampling density, location strategy and sampling time interval that give a statistically reliable representation of the overall noise level within each 1 km² square.

4.6.1 Survey Period

The weather conditions required for noise surveillance limit the noise survey period to the summer period when wind speeds and rainfall are generally lower.

Fothergill (FOT 77) found a statistically significant variation in noise levels for $L_{A10,18hour}$ and for $L_{Aeq,24hour}$ when he measured noise levels at six sites for one-week periods in three seasons (November, March and July). In general, the July noise levels were lower than those of the other two periods. Fothergill states that although the variations in noise are significant, the changes are not large and a single measurement of $L_{A10,18hour}$ or $L_{Aeq,24hour}$ will give a result within ± 1 dB(A) of the long term average in about 60% of cases and within ± 3 dB(A) in 95% of cases. Fothergill attributes 1 dB(A) of the variation to changes in traffic flow.

However, Griffiths *et al.* (GRI 80), found that, in general, the variations in noise levels at different times of the year were smaller than those found by Fothergill. Griffiths *et al.* took $L_{A10,18hour}$ measurements at six sites at different times of the year and found that typically the seasonal variations were approximately 2 dB(A).

Both of these studies have examined a very limited number of sites and they have given different results. It is, therefore, uncertain whether there will be any significant seasonal bias to noise data gathered throughout the summer period.

4.6.2 Sampling Density

The number of measurement locations necessary to give a statistically reliable representation of the overall noise levels within a 1 km² square will be a function of the 1 km² square's homogeneity and the expected variation in the statistical noise indices (L_{Aeq} , L_{A10} , and L_{A90}) within the area.

As L_{A10} is more dependent on local noise sources than L_{A90} it will exhibit a higher degree of spatial variance and will require a higher sampling density (SAF 73 and POC 79).

Senko and Kirshnan (SEN 71) calculated that, in New York, a sampling density of twenty-five sites in a square mile would produce an average L_{A90} noise level with an accuracy of 1.2 dB(A) at the 95% confidence level. This estimation is based on the assumption that L_{A90} is normally distributed between locations and that the standard error was 5 dB(A).

The sampling density used by Senko and Kirshnan is equivalent to the twenty sites per 1 km² square used by Pocock (POC 79). It produced values of L_{A90} with an accuracy of ± 1.6 dB(A) and a standard error of 5.2 dB(A) in the West Midlands. This confirms the estimate given by Senko and Kirshnan (SEN 71).

Pocock found that the standard deviation for L_{A10} was 6.9 dB(A) and thus a higher sampling density is required to produce an average L_{A10} measurement with the same accuracy as for L_{A90} .

The survey technique used to partially calibrate the prediction matrix in the proposed research uses a sampling density of twenty-five sites per 1 km² square.

This will reduce the possibility that the typical levels of L_{Aeq} , L_{A10} and L_{A90} are distorted by a single atypical measurement or measurement site and may improve the models accuracy in predicting L_{Aeq} and L_{A10} .

4.6.3 Location of Measurement Positions

Measurement positions within each 1 km² square could be selected by:

- Choosing approximately equally spaced measurement positions throughout the 1 km² square (e.g. at the intersections of grid lines on a map).
- Choosing a measurement position whose noise characteristics are representative of the average noise level of the 1 km² square (e.g. taking account of local shielding effects, topographical features etc.).
- Randomly choosing from a large set of approximately equally spaced measurement positions throughout the 1 km² square.

The first of these measurement position selection methods is used in this research as it treats the 1 km² square as if it were acoustically homogeneous and the results of such analysis can be treated statistically as independent samples, assuming no bias. Error can occur where a major noise source, such as a main road, coincides with one of the axes of the grid so that it is over represented by the sampling technique. The second method, although resulting in fewer noise measurements, may present difficulties when trying to select measurement positions that are truly representative of the typical noise climate within the 1 km² square. The third method could result in a concentration of measurement positions in one area and therefore an over representation of those local noise sources.

The twenty-five measurement sites are located at the twenty-five nodes of a grid superimposed on each 1 km² square as marked on Ordnance Survey maps.

The survey method selected aims to accurately portray the typical noise level within a 1 km² square, using a larger number of measurement positions, rather than less accurately defining the 1 km² square, using fewer measurement positions but sampling more 1 km² squares.

4.6.4 Site Measurement Method

It is not necessary for L_{Aeq} , L_{A10} and L_{A90} measurements to accurately represent the noise characteristics of each measurement location within a 1 km² square, as a single measurement that inaccurately portrays the locations

noise climate, will not significantly effect the arithmetic average noise levels calculated from all measurements at twenty-five measurement locations within the 1 km² square.

If only a few measurement sites were to be used to obtain the 1 km² square's typical noise level it would be more important that the each site is accurately portrayed by the individual measurements made.

It has already been stated that, at individual sites, the levels of L_{Aeq} , L_{A10} and L_{A90} have been found to be fairly constant between 10am. and 4pm. Thus repeat measurements at each site are not necessary.

To enable the large number of measurements, necessary to calibrate the prediction matrix axes, to be taken within the limited period of time available for noise surveillance and without facilities for simultaneous measurements, it is necessary to be able to complete the sampling of all the measurement sites within a 1 km² square in less than one days sampling (6 hrs) and preferably in half a day (3hrs).

This restriction indicates a measurement period of approximately five minutes at each of the twenty-five measurement sites.

Saffeer (SAF 73) compares values of L_{A10} and L_{A90} obtained from continuous five minute noise samples, taken within an hour, with the L_{A10} and L_{A90} values obtained from sampling the whole one hour period continuously. This comparison is made at two sites. Site 1 is in a residential area with large single and multi-family dwellings and site 2 is in an undeveloped woodland. Table 4.2 gives the results of this comparison along with the probability of a five minute sample of L_{A10} or L_{A90} having an error of ± 1 dB(A).

The residential area (site 1) has a rectangular distribution of measurements and the woodland area (site 2) has a skewed distribution.

This level of accuracy is assumed to be sufficient for the purposes of calibrating the prediction matrix.

Twenty-five sites each sampled for five minutes yields a total measurement period of two hours five minutes per 1 km² square.

The procedure used to measure noise at each site follows that described in the International Standard Organisation (ISO) standard for measuring

Table 4.2 Results from Saffeer's noise survey (SAF 73)

	Noise index	1 hour value	Range of 5 minute values	Probability that 5 min. reading has an error of ± 1 dB(A)
Site 1	L_{A10}	74	73 - 76	0.33
	L_{A90}	58	55 - 67	0.79
Site 2	L_{A10}	52	46 - 58	0.76
	L_{A90}	43	42 - 48	0.65

environmental noise (ISO 82).

The student measurements of L_{Aeq} and estimates of L_{A10} and L_{A90} (Appendix A) are taken for a period of approximately five minutes.

4.6.5 Equipment

The equipment used to measure noise levels at each site is the Computer Engineering Limited (CEL) 393B Precision Computing Sound Level Meter and Analyser.

This equipment complies with the following standard's specifications:

- BS 5969 type 1 sound level meters (BSI 81)
- BS 6698 type 1 sound level meters (BSI 86)

It allows for accurate, practical and simultaneous five minute measurements of each of the noise indices L_{Aeq} , L_{A10} and L_{A90} . The CEL 393B can be programmed to measure for a five minute period and the results are automatically stored in its memory. In addition to the noise indices above the CEL 393B automatically measures the median noise level (L_{A50}), the maximum noise level (L_{Amax}) registered in the five minute period, and 'Taktmaximal' 3 seconds (L_{t3}) and 'Taktmaximal' 5 seconds (L_{t5}) which are noise indices used in Germany. L_{A50} and L_{Amax} are recorded along with the chosen statistics L_{Aeq} , L_{A10} and L_{A90} . The 'Taktmaximal' measurements

have not been recorded as they are not used to assess noise in the United Kingdom and would therefore be of no practical use in this model.

The noise floor of the CEL 393B was checked by placing the meter in an anechoic chamber and recording 5 minute L_{Aeq} , L_{A10} , L_{A50} , L_{A90} , and L_{Amax} with no external noise source. The meter readings during this period were:

$$L_{Aeq}=24.1 \text{ dB(A)}$$

$$L_{A10}=24.0 \text{ dB(A)}$$

$$L_{A50}=24.0 \text{ dB(A)}$$

$$L_{A90}=23.5 \text{ dB(A)}$$

$$L_{Amax}=24.4 \text{ dB(A)}$$

4.6.6 Pilot Noise Survey

A pilot noise survey was used to test the feasibility of the measurement method, given the operational and theoretical demands and constraints, and to highlight any improvements that could be made to the survey technique.

Method

A CEL 393B Sound level meter was used to measure $L_{Aeq,5min}$, $L_{A10,5min}$, $L_{A50,5min}$, $L_{A90,5min}$ and $L_{Amax,5min}$ in a single 1 km² square in Milton Keynes.

Two methods of conveyance between sites were compared:

1. Walking between sites
2. Cycling between sites

and the sound level meter's response under a number of different wind conditions was also investigated.

All noise measurements were recorded at each site, on pilot noise survey report forms, along with the primary and secondary sources of noise contributing to those measurements. Primary and secondary noise sources were subjectively judged by ear.

Results

The pilot noise survey confirmed that five minute measurements at each of the twenty five sites within a 1 km² square can be obtained in less than one day.

A 1 km² square can be sampled in just over half a day (3.25 hours) if a bicycle is used to travel the shortest route between measurement sites provided that there are no delays and that the weather conditions remain suitable.

The sound level meter tends to overload at wind speeds greater than Beaufort 5 (Table 4.3). In particularly quiet areas, where a lower dB(A) range setting is required, the meter tends to overload at wind speeds greater than Beaufort 4. The wind speed was also found to vary sometimes considerably between sites.

The presence of the researcher within an area was found to alter the ambient noise level on occasions e.g. dogs barking at the surveyor, or people asking questions whilst a measurement was being taken. These disturbances would produce an unrepresentative measure of the ambient noise level normally found at that site.

Other unusual circumstances would also be unrepresentative of the typical noise levels at a particular location e.g. the once weekly household refuse collection by heavy motorised vehicle on an otherwise very quiet residential road.

Conclusions

A bicycle would be used to travel between measurement sites by the shortest route.

Measurements would be taken at Beaufort ratings of 5 or less in noisy areas and at Beaufort ratings of 4 or less in quieter areas.

The Beaufort wind speed would be recorded at each measurement site.

Measurements would be discounted if affected by the researcher disturbing the environment around her or by unusual circumstances. The measurement would then be repeated when the conditions were more representative.

The CEL 393B proved to be a practical sound level meter for the purposes of the research when mounted in a holder positioned at the front of the bicycle used for transport at each site.

4.6.7 Summary of Survey Method

Site Selection

Twenty-five measurement sites are selected within each 1 km² square as marked on Ordnance Survey maps. The selection is made using a grid overlay with each measurement site being located at the nodes of the grid. Every effort was made to measure noise levels at these locations. However, some of these measurement sites were inaccessible, i.e. located on top of a building. In these cases an alternative measurement site was selected with similar noise characteristics close to the original location.

Measurement Technique

Each sample site is sampled once for a five minute period. During this period the sound level meter records simultaneous measurements of L_{Aeq} , L_{A10} , L_{A50} , L_{A90} and L_{Amax} . These measurements are recorded on noise survey report forms (Figure 4.1).

The order in which the measurement sites are sampled is determined by the shortest route between sites.

A bicycle is used to travel between sites. The measurement procedure used at each site conforms to that described in the ISO standard 1996/1 (ISO 82).

The meter is calibrated daily and the battery voltage is checked prior to each measurement and replaced when the voltage falls below the manufacturer recommended minimum.

Valid Data

Measurements will not be taken or recorded where the surveyor has disturbed the ambient noise climate or where the noise level during the five

Figure 4.1 Noise survey data sheet

Date:

1 km² square no:

Grid reference:

1 km² square name:

Wind direction:

[illegible]

Table 4.3 Descriptors of the Beaufort Scale of wind force

Beaufort	Wind	Effect of wind observed on land
0	Calm	Calm; smoke rises vertically.
1	Light air	Smoke drift indicates the wind direction vanes do not move.
2	Light breeze	Wind felt on face; leaves rustle; vanes begin to move.
3	Gentle breeze	Leaves, small twigs in constant motion; light flags extended.
4	Moderate breeze	Dust, leaves and loose paper raised up; small branches move.
5	Fresh breeze	Small trees in leaf begin to sway

minute period is obviously unrepresentative.

Wind

All measurements are taken at wind speeds with Beaufort ratings of 5 or less.

This range of wind speeds is in accordance with those specified by CEL for the CEL 3482 wind shield used in conjunction with the CEL 393B sound level meter and those wind speeds found practical during the pilot noise survey.

Table 4.3 gives the descriptors used to visually assess the wind speed at each measurement site (MET 83).

The wind direction is also recorded so that wind induced enhancement or reduction of a source's noise level can be detected during data analysis.

Humidity

Sound level reduction due to moisture in the air is small and frequency dependant. At 20°C and 50% humidity the extra attenuation due to humidity can be expressed as Equation 4.2 (KUR 71).

$$Ea = 0.148f^2r10^{-8} \quad (4.2)$$

Where:

Ea = Excess attenuation (dB)

f = frequency Hz

r = range m.

An appreciable reduction is only found at high frequencies above 2kHz when the excess attenuation due to humidity at 500m will be 2.96 dB. The excess attenuation will be even less when expressed in overall dB(A) and within the error range of the proposed model. Attenuation at higher frequencies will be greater than at 2 kHz but this effect will not be important to this study as the human ear is less sensitive at these higher frequencies and thus the difference in dB(A) will be very small and the typical ambient spectra do not contain appreciable energy above 8 kHz. The frequency band of human hearing is 20 Hz to 20,000 Hz.

Noise measurements can be taken in moist and humid conditions. However the CEL 393B sound level meter is unsuitable for use in rain and therefore no measurements can be taken in wet weather.

Chapter 5

Summary of Noise Model Calibration Data

5.1 Summary of Noise Survey

5.1.1 Duration of Noise Survey

The noise survey data used to partially calibrate the prediction model were collected between 24th. April 1986 and 17th. October 1986.

The three case study areas were surveyed at different times during this period. The distribution of measurements over the survey months are shown for each case study area in Figure 5.1.

5.1.2 Sample Size

A total of 1,075 individual simultaneous five minute measurements of L_{Aeq} , L_{A10} , L_{A50} , L_{A90} and L_{Amax} were taken during the survey period. A total of forty-three 1 km² squares were surveyed.

The number of 1 km² squares surveyed in the two axes of the prediction matrix and the number in each of the case study areas are given in Table 5.1.

There are no residential 1 km² squares that have a vehicle density of less than 500 vehicles km/hr/km² (10 am. - 4 pm.) within any of the three case study areas.

Very few 1 km² squares have a vehicle density classification of 2001 - 4000 vehicle km/hr/km² and a land use category of commercial, residen-

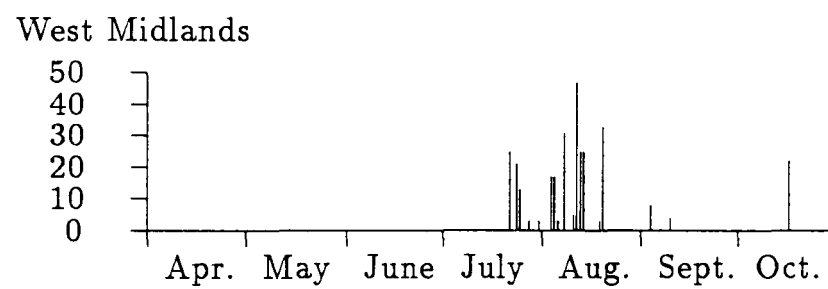
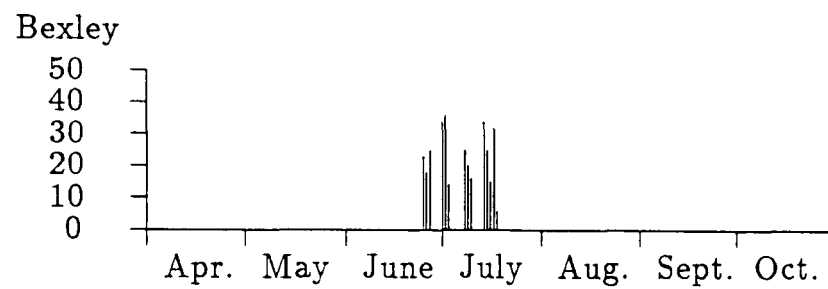
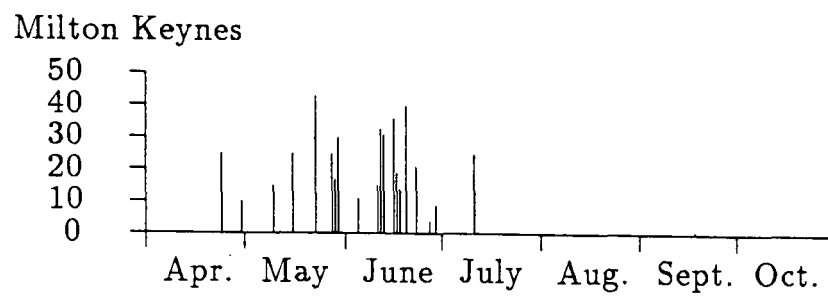


Figure 5.1 Number and distribution of measurements during the noise survey period.

Table 5.1 Number of 1 km² squares surveyed in each of the matrix axes

Land use		Traffic density				
		0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space	Total				3	
	M.K.				3	
	LBB.				0	
	WMMC.				0	
Residential	Total	0	5	8	7	4
	M.K.	0	2	4	3	0
	LBB.	0	2	2	3	2
	WMMC.	0	1	2	1	2
Commercial	Total				1	
	M.K.				1	
	LBB.				0	
	WMMC.				0	
Industrial	Total				5	
	M.K.				2	
	LBB.				1	
	WMMC.				2	
Residential/ Commercial	Total				1	
	M.K.				1	
	LBB.				0	
	WMMC.				0	
Residential/ Industrial	Total				5	
	M.K.				2	
	LBB.				2	
	WMMC.				1	
Commercial/ Industrial	Total				1	
	M.K.				0	
	LBB.				0	
	WMMC.				1	
Residential/ Commercial/ Industrial	Total				3	
	M.K.				0	
	LBB.				1	
	WMMC.				2	

tial/commercial or commercial/industrial. Each of these area-type categories has only one 1 km² square to represent it. Single 1 km² squares may be unrepresentative of their classification. The data gathered from these 1 km² squares are not used to test those research hypotheses that require an accurate portrayal of an area-type's typical noise climate. However, the data will be used to explore other aspects of the research.

5.1.3 Spatial Distribution of Sample Squares Surveyed

Figures 5.2 to 5.4 show the spatial distribution of the 1 km² squares surveyed in Milton Keynes, Bexley, and the West Midlands.

5.2 Wind Speed Correction Factor

Figure 5.5 gives the number of measurements taken under the various wind conditions described by the Beaufort Scale 0 to 5.

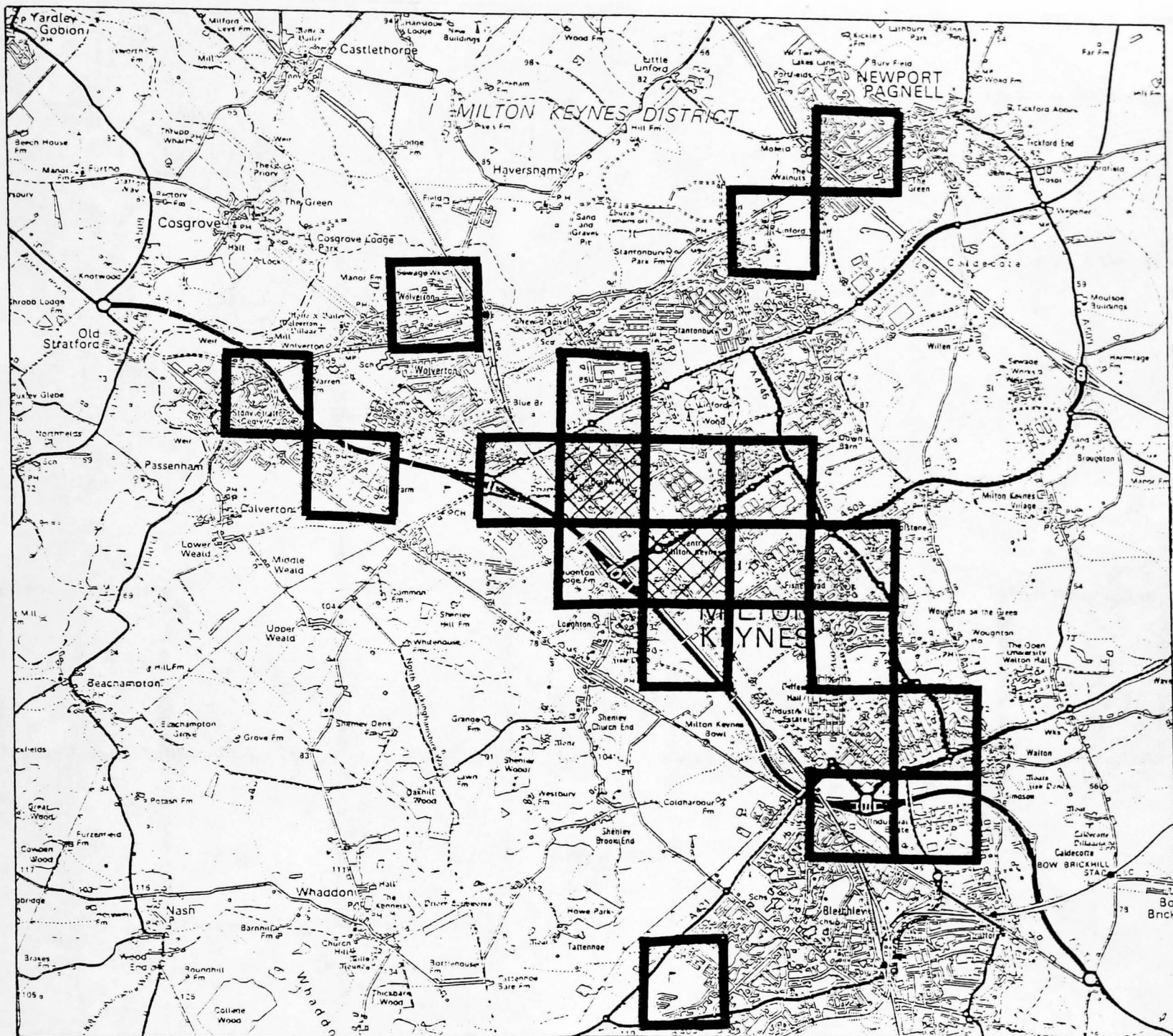
It is well documented that wind speed affects ambient outdoor noise levels. The speed of sound propagation is enhanced in the downwind direction of a source and reduced in the up wind direction of a source. The increased wind speed gradient with height above ground tends to reduce noise levels upwind of a source and enhance noise levels downwind of a source as sound rays are bent upwards and away from the receptor upwind and bend downwards towards the receptor downwind of the source. The mechanical action of wind on non-rigid structures also increases the ambient noise levels, eg leaves rustling, whistling around buildings etc.

If we compare measurements taken under different wind conditions an error due to wind effects will be introduced into the model.

5.2.1 Pococks Wind Correction Model

Pocock (POC 79) tried to eliminate this source of error by correcting his data to light wind conditions.

He used regression analysis to develop models for L_{A10} and L_{A90} from repeat measurements at sites within the West Midlands region, under different



AREAS NOT SURVEYED

Figure 5.2 Spatial distribution of squares sampled in Milton Keynes

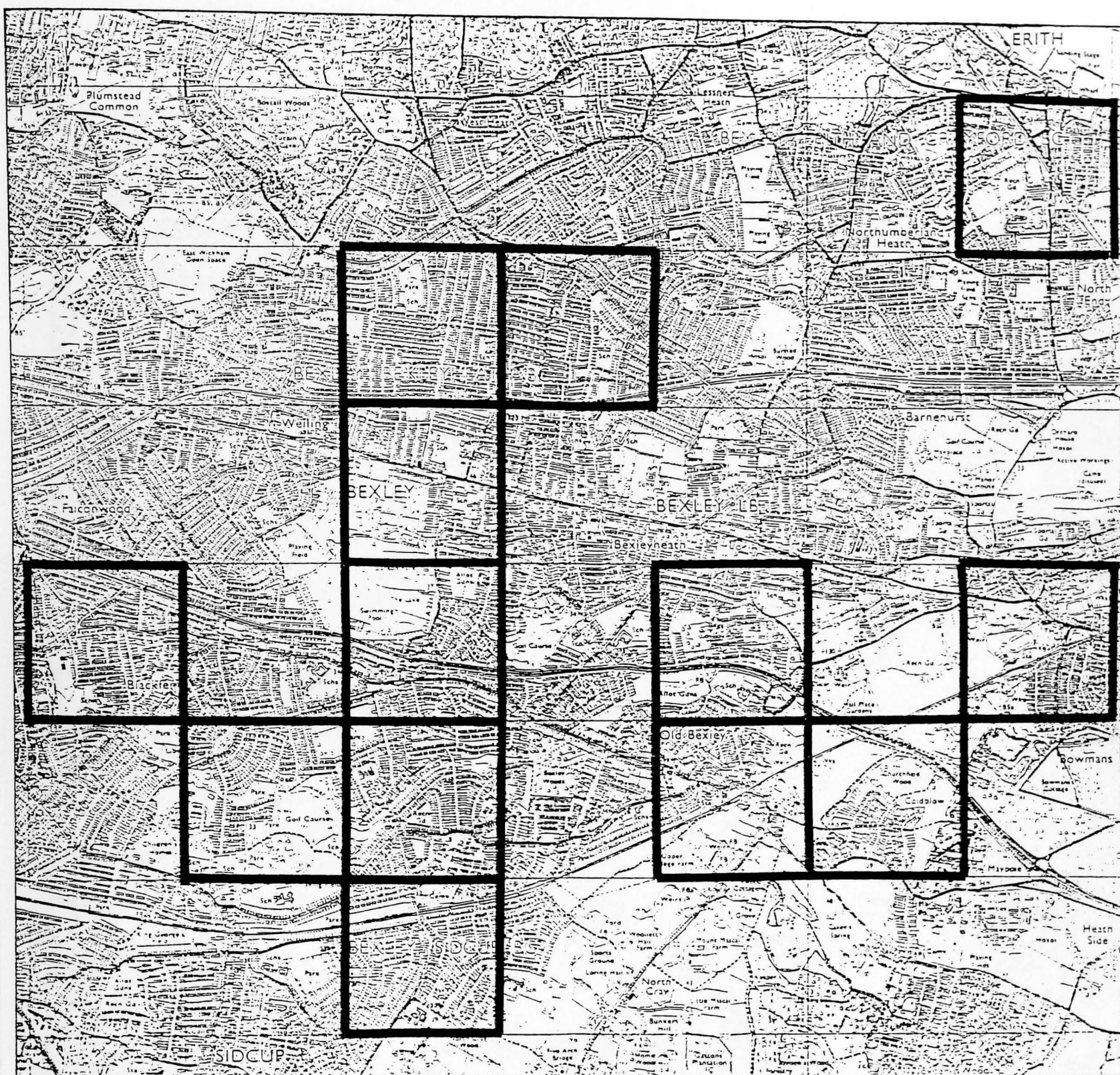


Figure 5.3 Spatial distribution of squares sampled in Bexley.

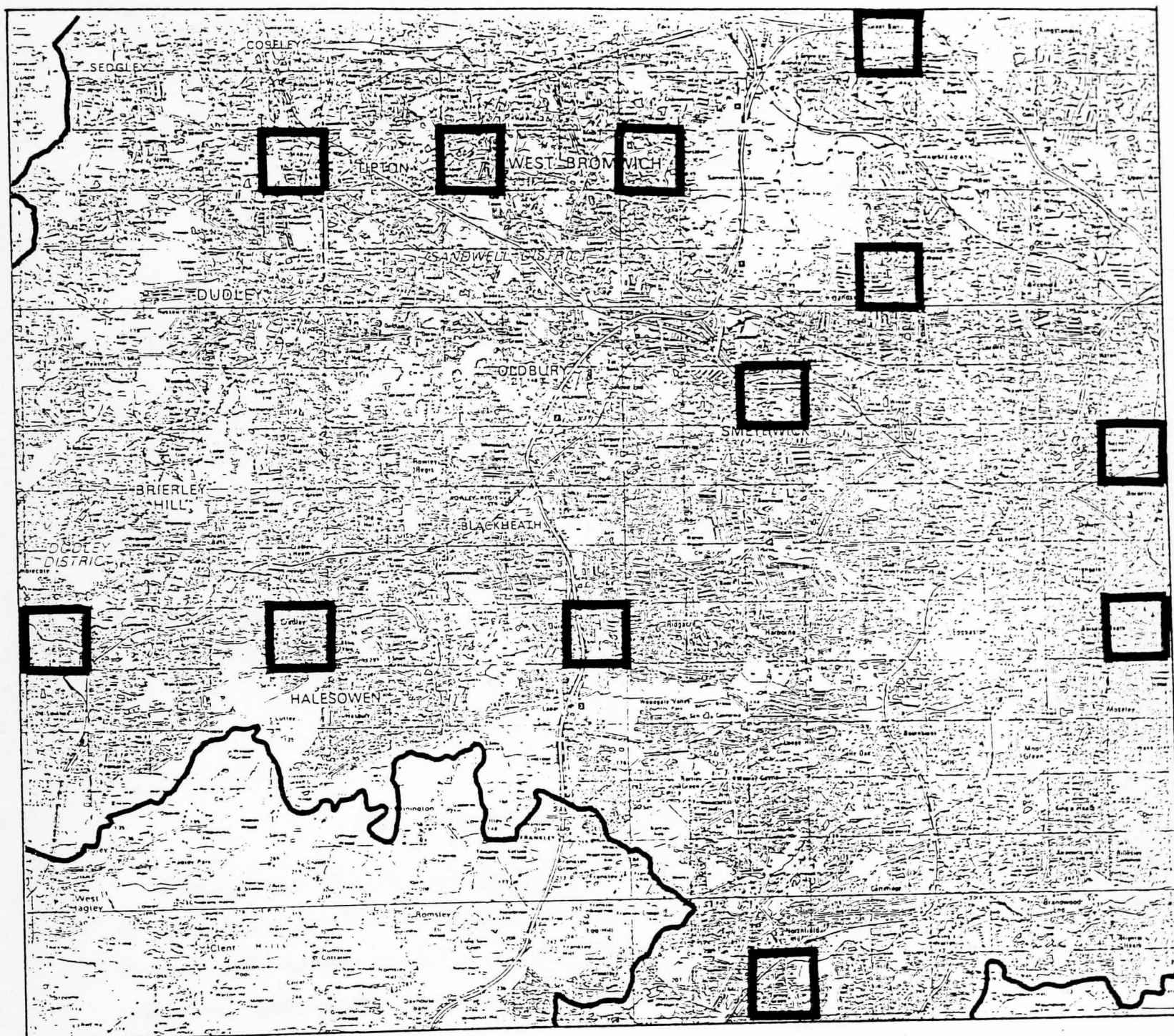


Figure 5.4 Spatial distribution of squares sampled in the West Midlands.

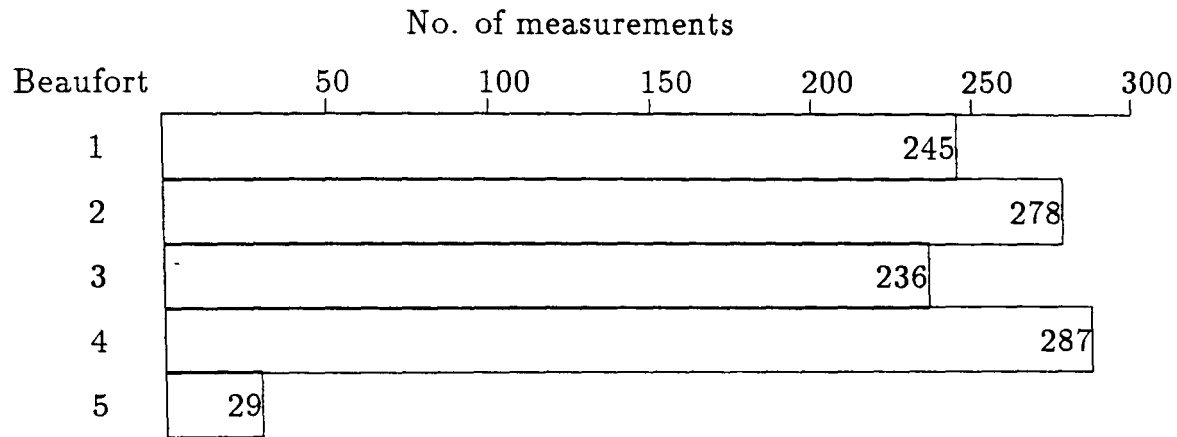


Figure 5.5 Frequency of measurements under different wind conditions

wind conditions.

The two empirical models for L_{A10} and L_{A90} predict the numerical increase in noise levels ($dN_{L_{A10}}$, $dN_{L_{A90}}$) due to the increase in wind speed represented by the Beaufort rating (B). The model corrects to light wind conditions and therefore is only applied to measurements taken in wind conditions above Beaufort 2.

The equations are:

$$dN_{L_{10}} = 0.15(B - 2)\left(\frac{75 - L_{10}}{10}\right)^2 \quad (5.1)$$

$$dN_{L_{90}} = 0.13(B - 2)\left(\frac{75 - L_{90}}{10}\right)^2 \quad (5.2)$$

Pocock found that, by correcting his data to light wind conditions, 90% of the variance in noise level between the arithmetic means of his 1.25 km² squares could be accounted for and 35% of the variance in noise levels at individual measurement sites could be accounted for by the general effects of wind speed.

Given the reduction in variance and the reduction in model error produced by applying a wind correction factor to Pocock's model it is desirable that the noise survey data collected in the proposed research should also be corrected for varying wind speeds.

The noise survey methodology used in this research does not allow for the development of a wind correction model as no repeat measurements were taken under different wind conditions. General trends in noise levels with varying wind speeds can not be inferred from the data collected as the dynamic range of 30 dB(A) setting on the sound level meter used dictated that quiet areas could not be surveyed on days when the wind gusts exceeded Beaufort rating Force 4 as defined in Table 4.3.

5.2.2 Validation of Pocock's Wind Correction Model for National Application

Pocock's regional wind speed correction model for correcting L_{A10} and L_{A90} to light wind conditions is tested to determine whether it could be used to correct data collected on a national scale.

The national noise measurements used to test the models validity on a national scale are supplied by the Open University undergraduate students taking the course 'T234 Environmental Control and Public Health' (Appendix A). The data supplied are summarised in Table 5.2.

The proposed prediction model also requires a wind correction model for the L_{Aeq} noise index. The student data are also used to explore whether Pocock's wind speed correction factor for L_{A10} can also be used to correct L_{Aeq} to 'light' wind conditions.

The student data are corrected for wind speed using Equation 5.1 for L_{Aeq} and L_{A10} and Equation 5.2 for L_{A90} and compared with the uncorrected student data. The results are summarised in Table 5.2 and in Figure 5.6.

Although the correction for wind speed seems to reduce the L_{A10} and L_{A90} noise measurements taken at Beaufort 3 and 5 and the L_{Aeq} measurements taken at Beaufort 5 so that they are closer to the average noise measured at Beaufort 1 and 2, there is little standardisation of the measurements at Beaufort 4. These variations in effect may be due to:

- the small number of measurements taken at Beauforts 4 and 5 (forty-nine and sixty-four respectively compared with one hundred and thirty-

Table 5.2 Arithmetic means and standard deviation of student measurements at different wind speeds.

(a) Uncorrected for wind

	Wind Strength (Beaufort Scale)					
	1	2	3	4	5	All
L_{Aeq}	49.7 (9.05) N = 58	52.8 (8.43) N = 128	52.4 (8.29) N = 109	51.8 (7.84) N = 49	54.3 (7.65) N = 63	52.4 (8.36) N = 407
L_{A10}	53.9 (10.57) N = 59	55.9 (9.13) N = 134	56.2 (8.44) N = 110	55.4 (9.40) N = 49	58.0 (8.31) N = 64	55.9 (9.11) N = 416
L_{A90}	41.4 (8.17) N = 59	43.1 (7.59) N = 134	44.1 (7.57) N = 110	43.8 (6.11) N = 49	45.8 (6.13) N = 64	43.6 (7.38) N = 416

(b) Corrected for wind using Pocock's correction factors

	Wind Strength (Beaufort Scale)					
	1	2	3	4	5	All
L_{Aeq}	49.7 (9.05) N = 58	52.8 (8.43) N = 128	51.6 (8.81) N = 109	50.00 (8.71) N = 49	52.1 (8.95) N = 63	51.6 (8.77) N = 407
L_{A10}	53.9 (10.57) N = 59	55.9 (9.13) N = 134	55.5 (8.88) N = 110	54.0 (10.27) N = 49	56.4 (9.49) N = 64	55.3 (9.47) N = 416
L_{A90}	41.4 (8.17) N = 59	43.1 (7.59) N = 134	42.8 (8.12) N = 110	41.1 (6.98) N = 49	42.3 (7.51) N = 64	42.4 (7.74) N = 416

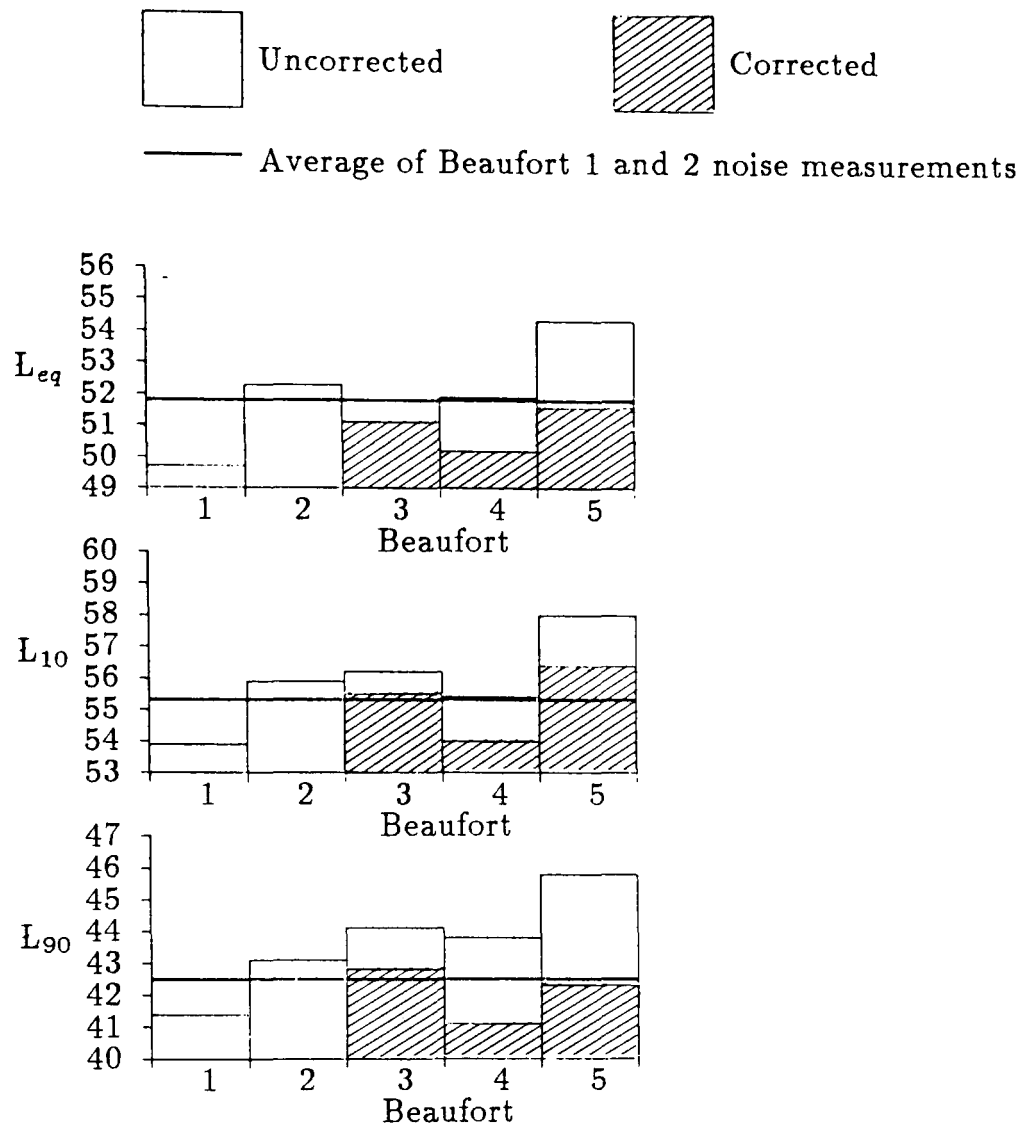


Figure 5.6 Comparison of student data corrected and uncorrected for different wind conditions

four for Beaufort 2) and/or

- the various Beaufort categories contain different subsets of area-types

These two factors may account for the apparent differences in the effects of Pocock's wind correction factor (POC 79) at differing wind speeds. If the wind is gusting for 10% or more of the time L_{Aeq} and L_{A10} measurements will be effected.

5.2.3 Time Weighting Sound Level Meter Setting

The ISO standard 1996/1 - 1982 (E) (ISO 82) specifies that a slow time weighting setting should be selected when measuring environmental noise.

Due to an oversight earlier on in the noise survey, ten of the 1 km² squares surveyed in Milton Keynes were surveyed with the sound level meter set on fast response. The subsequent 1 km² squares were surveyed as recommended in ISO standard 1996/1. An experiment was conducted to establish whether the mean of measurements taken under 'fast response' are comparable with the 'slow response' measurements.

A CEL 393B Computing Sound Level Meter and a Brüel & Kjær Environmental Noise Analyser were programmed to measure twenty-five consecutive measures of $L_{Aeq,5min}$, $L_{A10,5min}$, and $L_{A90,5min}$. The CEL 393B was set to 'fast response' and the environmental noise analyser set to 'slow response'. The internal clocks of the two pieces of equipment were synchronised so that they measured noise during the same time period.

The measurements were taken three metres from the carriage way of a fairly busy dual carriageway in Milton Keynes between 1005 and 1210 hours on a normal working weekday.

The variability in the traffic flow and composition during any 5 minute period provided a fluctuating noise source equivalent to the most variable of noise sources encountered during the main noise survey.

The difference between the arithmetic averages of the 'fast response' measurements and the 'slow response' measurements of L_{Aeq} , L_{A10} , L_{A90} are shown in Table 5.3.

The CEL 393B's Measurements occasionally registered an overload, these measurement periods have been omitted from the comparison (hence 23 measurements).

The largest difference between the fast and slow response measurements is 0.9 dB(A) and well within the notional tolerable error for the predictive model of ± 1.7 dB(A).

Table 5.3 Comparison of measurements on fast and slow meter settings.

	Fast Response			Slow Response		
	CEL 393B computing sound level meter			Brüel & Kjær environmental noise analyser		
	L_{Aeq}	L_{A10}	L_{A90}	L_{Aeq}	L_{A10}	L_{A90}
Mean	74.6	78.0	58.6	74.9	78.9	59.4
Standard Deviation	4.0233	3.5995	4.1954	1.3532	0.2144	0.1925
Number of Measurements	23	23	23	23	23	23

5.2.4 Temporal Variation in Noise Levels

Seasonal

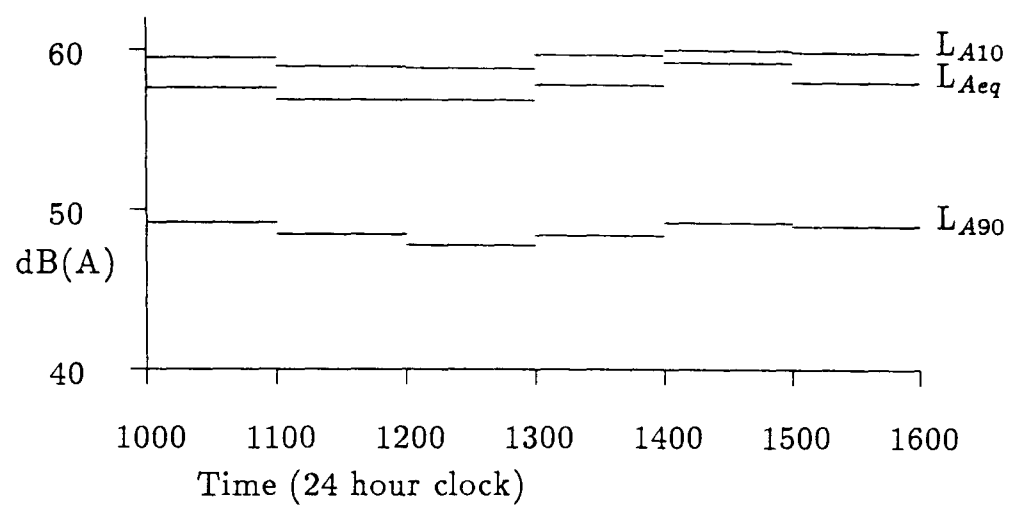
As discussed in Section 4.6.1 it is uncertain whether the different sampling periods used for each case study area would introduce a seasonal bias to the noise data collected. If there is a seasonal bias to the data it is expected to be small.

10 am. - 4 pm. weekdays

It was assumed in Section 3.4.1 that noise levels are fairly constant between 10 am. and 4 pm.

The results from this research indicate that this assumption is correct. Figure 5.7 shows the average hourly wind corrected levels for L_{Aeq} , L_{A10} , L_{A90} and $(L_{A10} - L_{A90})$ for all noise measurement sites surveyed. The measurements used to derive this graph are not from a single measurement site and therefore can only be used as an indicator of the diurnal variations in noise levels as the noise measurements in some hours may have been taken from quieter or noisier areas than in other hours.

The maximum deviation of the hourly average of each of the variables L_{Aeq} , L_{A10} , L_{A90} and $(L_{A10} - L_{A90})$ from the mean of the total period 10



Time period	No. of measurements in the hour.
10 am. to 11am.	187
11am. to 12am.	202
12am. to 1pm.	209
1pm. to 2pm.	208
2pm. to 3pm.	158
3pm. to 4pm.	111

Figure 5.7 Temporal variations in noise levels weekdays 10am. to 4pm.

Table 5.4 Maximum deviation of hourly mean from daytime mean

Variable	Maximum deviation of hourly mean from daytime mean (10 am. - 4 pm.) dB(A)
L_{Aeq}	1.5973
L_{A10}	0.9443
L_{A90}	0.8398
$(L_{A10} - L_{A90})$	1.0490

am. - 4 pm. are shown in Table 5.4.

This small degree of variability during the daytime period is well within the tolerances of the proposed model specified in Chapter 3.

5.3 Averaging Statistic Selection

Care must be taken in selecting a statistical average, of the twenty five noise measurements collected from each 1 km² square, that gives a good representation of the typical noise level within the 1 km² square.

5.3.1 Logarithmic Versus Arithmetic Averages

The decibel is a logarithmic scale for measuring sound pressure level (SPL) and is defined by the equation below.

$$SPL = 20 \log\left(\frac{p}{p_0}\right) \quad (5.3)$$

Where:

- p = root-mean-square sound pressure in Pascals
- p_0 = reference root-mean-square sound pressure
(generally 2×10^{-5} Pa)

Logarithmic averages are used to determine the overall noise level produced by the combination of a number of noise sources whose individual decibel output are known.

Logarithmic averages are not suitable for determining the typical noise level within a 1 km² square, as they will be biased towards the higher measurements. This point can be illustrated using a simple numerical example:-

If we consider the noise measurements of 55 dB(A), 60 dB(A), 65 dB(A) and 70 dB(A) and calculate the arithmetic mean and median and the logarithmic mean and median of these four measurements, we have the following results:-

$$\begin{aligned}\text{Arithmetic mean} &= 62.5 \text{ dB(A)} \\ \text{Logarithmic mean} &= 64.2 \text{ dB(A)} \\ \text{Arithmetic median} &= 62.5 \text{ dB(A)} \\ \text{Logarithmic median} &= 62.9 \text{ dB(A)}\end{aligned}$$

(55 dB(A) \equiv 0.01125 Pa, 60 dB(A) \equiv 0.02 Pa, 65 dB(A) \equiv 0.03557 Pa, and 70 dB(A) \equiv 0.06325 Pa.)

The higher noise measurements are not typical of the group of four measurements, yet they bias the logarithmic averages in their direction.

5.3.2 Characteristics of the Arithmetic Mean, Median and Mode as Averaging Statistics.

Three arithmetic averages could be used to represent the typical noise levels within each 1 km² square:

1. arithmetic mean
2. arithmetic median and
3. arithmetic mode.

The statistical average that is the most accurate portrayal of the 1 km² square's typical noise level, will depend on the shape of the distribution of measurements within each 1 km² square and how stable the statistic is where a low number of measurements are being studied.

If the measurement distribution is normal, the mean, median and mode will all be equal. However, if the distribution is skewed the arithmetic mean

Table 5.5 Skewness of sample square measurements

	L_{Aeq}	L_{A10}	L_{A90}	$(L_{A10} - L_{A90})$
Average 1 km ² skewness	0.592	0.687	0.851	0.814
Maximum negative 1 km ² skewness	-0.304	-0.216	-0.163	-0.084
Maximum positive 1 km ² square skewness	1.936	2.067	2.735	1.790

is biased in the direction of the skew and, in these cases, the arithmetic mean may be the best representative of the typical noise level with a 1 km² square.

The skewness (sk) of L_{Aeq} , L_{A10} , L_{A90} and $(L_{A10} - L_{A90})$ measurement distributions in each 1 km² square, have been calculated for each 1 km² square using the equation:

$$sk = \frac{\Sigma(x^3/N)}{(\sqrt{\Sigma(x^2/N)})^3} \quad (5.4)$$

where:

- x is the deviation of the noise index measurement from the mean and
- N is the number of cases.

The average skewness found in the 43 sites for the different noise indices, are given in Table 5.5 along with the maximum negative skewness and maximum positive skewness for each noise index.

These figures indicate that the data in each 1 km² square are, generally, slightly positively skewed.

The arithmetic mean will be influenced by unusually high or low noise measurements that may be unrepresentative of the 1 km² square.

This can be illustrated using the skewed distribution of measurements found in one of the 1 km² square surveyed. Figure 5.8 shows the distribution

Table 5.6 Arithmetic means and medians for 25 and 24 measurement sites within sample site number 21

	All 25 sites	24 sites excluding the noisiest	change in dB(A)
Arithmetic mean	56.992	55.837	1.155
Arithmetic median	54.917	54.638	0.279

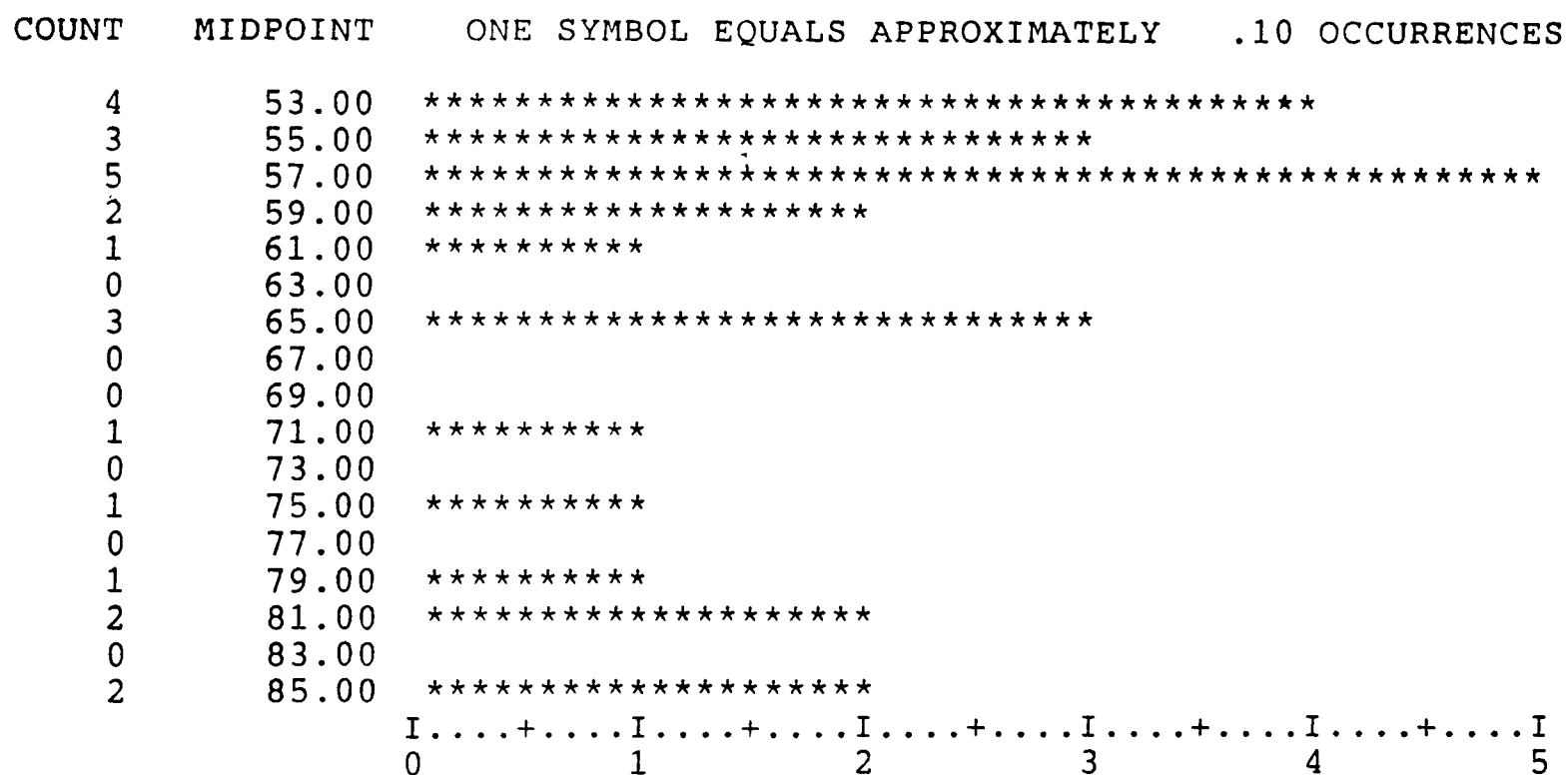


Figure 5.9 L_{A10} measurement distribution for the sample square with the largest difference between the mean and median values.

If we consider the seven noise measurements greater than 70 dB(A), five of the measurements were taken near to major roads running through the area, one was close to the railway track and the other was near a mechanical digger. With the exception of the site near the mechanical digger, these sites are representative of their 1 km² square. The median takes no account of these high readings whereas the mean is skewed in their direction.

An alternative to the arithmetic mean and median is the arithmetic mode. This measure of the distribution is, however, very unstable when the population of measurements is small and is therefore not a reliable measure of the 1 km² square's typical noise level.

Previous researchers have used either the arithmetic mean (POC 79) or the median (MOC 67) to determine the typical noise level within an area-type.

In this research, the arithmetic mean will be used to represent the typical noise level within each 1 km² square as the effect of a few un-representatively high or low measurements will be very small when calculating the arithmetic mean of twenty-five site measurements.

5.4 Measurement Distribution in Each Sample Square

Table 5.7 gives summary statistics for the distribution of noise measurements within each 1 km² square averaged over the forty-three 1 km² squares sampled, along with the maximum and minimum values of each 1 km² square's statistic.

In general the shape of the measurement distribution is slightly skewed and slightly leptokurtic. However, the average distribution of measurements within the 1 km² square has an approximately normal distribution.

The large range in kurtosis is partially due to the instability of this variable for small sample numbers.

As expected the L_{A10} measurements have the highest average standard deviation of 8.2 dB(A) followed by L_{Aeq} (average s.d. = 7.7 dB(A)), L_{A90}

Table 5.7 Measurement distributions found within the sample squares sampled

Variable		Wind Corrected			
		L_{Aeq}	L_{A10}	L_{A90}	$L_{A10} - L_{A90}$
Arithmetic median	Mean	56.3	58.1	47.3	9.5
	Min	45.0	49.0	35.0	5.0
	Max	65.0	67.0	56.0	15.0
Arithmetic mean	Mean	57.8	59.8	48.8	10.9
	Min	46.5	48.6	36.3	6.7
	Max	63.8	66.2	57.8	15.9
Standard deviation of arithmetic mean	Mean	7.7	8.2	6.0	5.3
	Min	1.3	1.9	0.6	3.1
	Max	10.6	10.9	8.5	7.0
Minimum measurement	Mean	45.2	46.7	39.5	3.6
	Min	34.4	36.5	31.0	0
	Max	51.9	53.3	46.7	7.0
Maximum measurement	Mean	75.4	78.6	63.9	23.2
	Min	61.6	64.7	43.5	14.9
	Max	84.8	87.5	80.4	30.0
Skewness	Mean	0.592	0.687	0.851	0.814
	Min	-0.304	-0.216	-0.163	-0.084
	Max	1.936	2.067	2.735	1.790
Kurtoise	Mean	0.271	0.444	0.948	0.323
	Min	-1.289	-1.235	-1.141	-1.385
	Max	5.004	6.199	10.550	4.002

(average s.d. = 6.0 dB(A)) and ' $L_{A10} - L_{A90}$ ' (average s.d. = 5.3 dB(A)). The large range in standard deviation, is due to some of the 1 km² squares being measured with the sound level meter set on 'fast response'.

5.5 Measurement Distributions in Each of the Prediction Matrix Cells

Tables 5.8 and 5.9 give:

- the mean of the standard deviations for the 1 km² square measurement distributions;
- the standard deviation of the above standard deviation mean;
- the mean of the skewness values for the 1 km² square measurement distributions;
- the standard deviation of the above skewness mean and
- the number of 1 km² squares

in each of the calibrated prediction matrix cells.

Table 5.8 Mean standard deviation of the sample square measurement distributions

Land use	Vehicle density (veh./km/km ²)	Number of sample square	Mean 1 km ² square standard deviation			
			L_{Aeq}	L_{A10}	L_{A90}	$L_{A10}-L_{A90}$
Residential	501 - 1000	N = 5	6.444	7.036	3.986	5.350
Residential	1001 - 2000	N = 8	7.711	8.026	5.416	5.245
Open space	2001 - 4000	N = 3	8.860	9.560	6.300	5.620
Residential	2001 - 4000	N = 7	7.503	7.887	6.409	5.166
Commercial	2001 - 4000	N = 1	6.410	7.080	3.250	5.620
Industrial	2001 - 4000	N = 5	8.532	8.562	6.788	5.660
Residential/ Commercial	2001 - 4000	N = 1	7.700	7.790	6.370	4.180
Residential/ industrial	2001 - 4000	N = 5	8.220	8.760	6.572	5.642
Commercial/ industrial	2001 - 4000	N = 6	9.470	9.640	7.660	6.380
Residential/ commercial/ industrial	2001 - 4000	N = 3	8.577	9.150	7.433	5.163
Residential	4001 - 8000	N = 4	6.685	7.250	5.725	4.468

Table 5.9 Mean skew in the sample square measurement distributions

Land use	Vehicle density (veh./km/km ²)	Number of sample squares	Mean 1 km ² square skewness			
			L _{Aeq}	L _{A10}	L _{A90}	L _{A10} -L _{A90}
Residential	501 - 1000	N = 5	0.677	0.823	0.520	0.720
Residential	1001 - 2000	N = 8	0.587	0.788	0.761	0.748
Open space	2001 - 4000	N = 3	0.690	0.716	0.882	0.997
Residential	2001 - 4000	N = 7	0.915	0.991	1.395	0.723
Commercial	2001 - 4000	N = 1	1.012	1.065	0.799	1.224
Industrial	2001 - 4000	N = 5	0.104	0.186	0.370	0.740
Residential/ commercial	2001 - 4000	N = 1	0.656	1.024	1.245	1.002
Residential/ industrial	2001 - 4000	N = 5	0.314	0.428	0.614	0.667
Commercial/ industrial	2001 - 4000	N = 1	0.289	0.319	1.116	1.174
Residential/ commercial/ industrial	2001 - 4000	N = 3	0.827	0.798	1.538	0.939
Residential	4001 - 8000	N = 4	0.593	0.538	0.700	1.028

5.6 Arithmetic Means of Mean Measurements Within Each of the Prediction Matrix Cells

Tables 5.10 to 5.13 give the arithmetic mean of the noise index values for each of the area-type classifications defined by the calibrated cells of the prediction matrix, along with the standard deviation of the mean in brackets and the number of 1 km² square used to calculate the typical noise index value (N).

It can be seen that there is only a small variation in noise levels between the majority of the area-types.

There is a larger range of noise levels in the residential land use axis than in the 2001 - 4000 veh. km/hr/km² traffic/road density axis of the matrix. This suggests that the traffic/road density categories may be a better predictor of noise levels than the land use categories.

The high noise levels in the open space category may be due to the absence of barriers to noise generated by traffic in those areas so that traffic noise will effect a larger majority of measurement locations than more built up areas.

As expected industrial areas have the highest levels of L_{Aeq} , L_{A10} and L_{A90} in the land use axis.

The value ($L_{A10} - L_{A90}$) has been linked to public annoyance (GRI 68). The results from the survey indicate that the variability in noise denoted by ($L_{A10} - L_{A90}$) is highest in lower traffic density areas and areas where residential land use is mixed with other forms of land use such as industry or commerce. It is therefore indicated that public nuisance due to noise will be most likely in these areas.

Table 5.10 Case study area wind corrected L_{Aeq} (10 am. to 4 pm.)

Land use	Traffic density (veh.km/hr./km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space				59.3 (3.2) N = 3	
Residential		52.4 (4.3) N = 5	57.3 (2.6) N = 8	56.4 (4.1) N = 7	59.2 (3.2) N = 4
Commercial				58.0 (-) N = 1	
Industrial				61.7 (2.4) N = 5	
Residential/ Commercial				60.2 (-) N = 1	
Residential/ Industrial				60.0 (1.4) N = 5	
Commercial/ Industrial				59.4 (-) N = 1	
Residential/ Commercial/ Industrial				57.0 (2.1) N = 3	

Mean L_{Aeq} for entire population 57.8 dB(A).

Standard deviation = 3.8

N = 43

Table 5.11 Case study area wind corrected L_{A10} (10 am. to 4 pm.)

Land use	Traffic density (veh.km/hr./km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space				61.1 (2.7) N = 3	
Residential		54.5 (4.1) N = 5	59.4 (2.4) N = 8	58.3 (4.3) N = 7	61.1 (3.9) N = 4
Commercial				60.9 (-) N = 1	
Industrial				63.3 (2.2) N = 5	
Residential/ Commercial				61.8 (-) N = 1	
Residential/ Industrial				62.0 (1.5) N = 5	
Commercial/ Industrial				61.4 (-) N = 1	
Residential/ Commercial/ Industrial				58.8 (1.6) N = 3	

Mean L_{A10} for entire population 59.8 dB(A).

Standard deviation = 3.7

N = 43

Table 5.12 Case study area wind corrected L_{A90} (10 am. to 4 pm.)

Land use	Traffic density (veh.km/hr./km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space				50.7 (2.6) N = 3	
Residential		42.4 (4.8) N = 5	46.5 (2.6) N = 8	47.7 (4.0) N = 7	53.1 (4.4) N = 4
Commercial				51.3 (-) N = 1	
Industrial				52.9 (2.0) N = 5	
Residential/ Commercial				51.8 (-) N = 1	
Residential/ Industrial				50.5 (1.2) N = 5	
Commercial/ Industrial				52.3 (-) N = 1	
Residential/ Commercial/ Industrial				48.5 (2.4) N = 3	

Mean L_{A90} for entire population 48.8 dB(A).

Standard deviation = 4.4

N = 43

Table 5.13 Case study area wind corrected ($L_{10} - L_{90}$) (10 am. to 4 pm.)

Land use	Traffic density (veh.km/hr./km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space				10.4 (0.8) N = 3	
Residential		12.1 (3.4) N = 5	12.9 (1.5) N = 8	10.6 (2.0) N = 7	8.0 (1.0) N = 4
Commercial				9.6 (-) N = 1	
Industrial				10.4 (1.0) N = 5	
Residential/ Commercial				9.9 (-) N = 1	
Residential/ Industrial				11.5 (2.3) N = 5	
Commercial/ Industrial				9.1 (-) N = 1	
Residential/ Commercial/ Industrial				10.3 (0.8) N = 3	

Mean $L_{A10}-L_{A90}$ for entire population 10.9 dB(A).

Standard deviation = 2.2

N = 43

5.7 Arithmetic Means of Median Measurements Within Each of the Prediction Matrix Cells

Tables 5.14 to 5.17 give the arithmetic means of the median noise levels within each sample square. Arithmetic means of these median values, have been calculated for each of the area-types defined by the noise prediction model and for the population as a whole. It can be seen that for the measurements as a whole, the standard deviation of the median values is larger than that for the arithmetic mean values (see Table 5.10 to 5.13). However, this is not the case for all of the area-type classifications. The arithmetic means of the median do not follow the same general pattern across the area-type categories shown in Tables 5.10 to 5.13.

The arithmetic mean has been chosen for the subsequent analysis.

Table 5.14 Case study area wind corrected L_{Aeq} (10 am. to 4 pm.) - arithmetic means of median values

Land use	Traffic density (veh.km/hr./km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space				55.7 (2.3) N = 3	
Residential		51.4 (4.7) N = 5	55.8 (3.9) N = 8	54.7 (4.2) N = 7	57.0 (3.7) N = 4
Commercial				56.0 (-) N = 1	
Industrial				61.4 (2.7) N = 5	
Residential/ Commercial				58.0 (-) N = 1	
Residential/ Industrial				59.2 (2.0) N = 5	
Commercial/ Industrial				57.0 (-) N = 1	
Residential/ Commercial/ Industrial				55.7 (3.5) N = 3	

Mean L_{Aeq} for entire population 56.3 dB(A).

Standard deviation = 4.2

N = 43

Table 5.15 Case study area wind corrected L_{A10} (10 am. to 4 pm.) - arithmetic means of median values

Land use	Traffic density (veh.km/hr./km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space				57.7 (0.6) N = 3	
Residential		54.0 (3.7) N = 5	57.4 (3.0) N = 8	56.6 (5.0) N = 7	59.0 (4.2) N = 4
Commercial				58.0 (-) N = 1	
Industrial				63.0 (2.9) N = 5	
Residential/ Commercial				59.0 (-) N = 1	
Residential/ Industrial				60.4 (1.5) N = 5	
Commercial/ Industrial				59.0 (-) N = 1	
Residential/ Commercial/ Industrial				56.7 (2.5) N = 3	

Mean L_{A10} for entire population 58.0 dB(A).

Standard deviation = 3.9

N = 43

Table 5.16 Case study area wind corrected L_{A90} (10 am. to 4 pm.) - arithmetic means of median values

Land use	Traffic density (veh.km/hr./km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space				48.0 (1.7) N = 3	
Residential		41.4 (5.1) N = 5	45.0 (3.4) N = 8	46.1 (4.1) N = 7	51.3 (4.3) N = 4
Commercial				50.0 (-) N = 1	
Industrial				52.0 (2.6) N = 5	
Residential/ Commercial				50.0 (-) N = 1	
Residential/ Industrial				49.2 (1.6) N = 5	
Commercial/ Industrial				50.0 (-) N = 1	
Residential/ Commercial/ Industrial				46.3 (2.1) N = 3	

Mean L_{A90} for entire population 47.3 dB(A).

Standard deviation = 4.5

N = 43

Table 5.17 Case study area wind corrected L_{A10} - L_{A90} (10 am. to 4 pm.) - arithmetic means of median values

Land use	Traffic density (veh.km/hr./km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space				8.3 (0.6) N = 3	
Residential		11.0 (3.4) N = 5	11.4 (1.9) N = 8	9.1 (2.5) N = 7	7.0 (1.4) N = 4
Commercial				8.0 (-) N = 1	
Industrial				9.2 (1.5) N = 5	
Residential/ Commercial				9.0 (-) N = 1	
Residential/ Industrial				10.2 (3.0) N = 5	
Commercial/ Industrial				7.0 (-) N = 1	
Residential/ Commercial/ Industrial				8.3 (0.6) N = 3	

Mean L_{A10} - L_{A90} for entire population 9.5 dB(A).

Standard deviation = 2.4

N = 43

Chapter 6

The Statistical Testing of the Research Hypotheses Relating to Noise

6.1 Introduction

Data from the noise survey of the three case study areas and the student survey are used to test the research hypotheses outlined in Section 3.5.

Wherever possible separate analyses are carried out on the two sets of data and the results compared to test whether the results from the data gathered from the Borough of Milton Keynes, London Borough of Bexley and the West Midlands are valid nationally.

6.2 Testing of General Hypothesis 1 - Noise

The hypothesis:

‘That variations in the noise indices are significantly associated with variations in the area’s demographic variables.’

is tested using two analysis methods.

Firstly the theoretical prediction matrix is tested using analysis of variance techniques. Separate analyses are carried out on the noise data gathered from the three case study areas and on the student data. The results from the two analyses of variance are compared.

Subsequently the two sets of data are used separately to build regression equations for predicting the noise indices L_{Aeq} , L_{A10} and L_{A90} using multiple regression analysis.

6.2.1 Analysis of the Theoretical Noise Prediction Matrix

A one-way analysis of variance test is used to test the theoretical prediction matrix as a model for predicting the noise indices L_{Aeq} , L_{A10} and L_{A90} .

This statistical technique compares the variance in the 1 km² square mean noise level within each of the area-type classifications, defined by the cells of the prediction matrix, with the variance in the area classification mean noise levels across all of the matrix cells that are calibrated with a sufficient number of 1 km² squares.

An F-test is performed on the results from the analysis of variance to test the null hypothesis that:

‘that there is no difference between the arithmetic means of the 1 km² square means representing each of the area-type classification defined by the calibrated cells of the prediction matrix.’

Three assumptions underlie the analysis of variance technique

- The individual 1 km² square should be selected on the basis of random sampling from a normally distributed population.
- The variance of the mean 1 km² square noise level within each of the area-type classifications should be homogeneous.
- The noise measurements representing the 1 km² squares should be independent so that they thereby yield independent variable estimates, and the ratio of within area classification variance and between area classification variances in noise will have an F distribution.

The analysis of variance technique is robust in respect of these assumptions and the data from the three case study area noise survey and the student noise survey used in the analyses do not significantly violate these

assumptions. The homogeneity of variance is tested using the Bartlett - Box F-test (BAR 37) and the Cochran C-test (COC 50). Normal and detrended normal plots are used to test the data for a F distribution.

6.2.2 Matrix Cell Selection Criteria for Inclusion in the Analysis of Variance Testing of the Prediction Matrix Model

To obtain meaningful results from the analysis of variance testing of the prediction matrix model only those matrix cells with noise index levels that are representative of their area-type classification can be included in the analysis.

The representative nature of the matrix cell noise indices will depend upon the number of 1 km² squares used to calibrate the cell, how many measurements are used to determine representative noise indices for each of those 1 km² squares, the quality of the individual measurements, how representative of their area-type classification are the individual 1 km² squares and the accuracy of the land use and traffic density data used to achieve the 1 km² square's area-type classification.

Three Case Study Area Data

The measurement representing the noise indices typical of a 1 km² square is the arithmetic average of 25, 5 minute measurements taken within that 1 km² square. Each measurement is taken using a Type 1 sound level meter.

These averages are therefore a good representation of the typical values of the noise indices found within that 1 km² square.

The major source of error in the representation of an area-type classification will be caused by using 1 km² squares that are not typical of their area-type classification (e.g. a 1 km² square with a small area of industrial land use which has an unusually high noise output).

As discussed in Section 3.4.2 a minimum of three 1 km² square are thought to be sufficient to calibrate each of the matrix cells.

Thus in the analysis of variance testing of the prediction matrix using the three case study area noise survey data, only matrix cells that are represented by three 1 km^2 squares are included.

Student Data

Single 5 minute measurements of L_{Aeq} , L_{A10} and L_{A90} , taken with a type 3 sound level meter, are used to represent the typical L_{Aeq} , L_{A10} and L_{A90} noise levels found within the 1 km^2 square centered upon the measurement site (see Appendix A). These single measurements are used to calibrate the cells of the prediction matrix.

The land use data used to define the 1 km^2 square's area-type classification are subjective assessments of the land use percentages within a 1 km^2 square made by the individual students. The traffic-road density variable is derived from the types of road found within the 1 km^2 square as described in Appendix B. Thus, the characterisation of each 1 km^2 square in terms of its area-type classification is subject to a much higher degree of error than in the more rigorous study of the three case study areas.

The accuracy of portrayal of the typical noise level within each of the 1 km^2 squares is greatly reduced by using only a single measurement to represent it. The three case study area's measurements show that the standard deviation of 25 measurements of L_{Aeq} , L_{A10} and L_{A90} taken within a 1 km^2 square can be as large as 10.6, 10.9 and 8.5 respectively.

The type of sound level meter is also of poorer quality (not an appreciable error for broad-band noise environments) and is used by relatively inexperienced operators.

Thus a much larger number of 1 km^2 squares are needed to represent each of the prediction matrix cells so that:

- the measurements that are unrepresentative of their 1 km^2 square, and
- the 1 km^2 squares that have been wrongly classified

do not have a large influence on the calculation of the noise indices typical of the area-type classification defined by the prediction matrix cells.

An analysis of variance test is carried out using the prediction matrix cells that are calibrated by 15 or more student measurements.

In theory it would have been possible to partially validate the area-based regression models by using other sources of noise data, e.g. the Watford Survey, the London Noise Survey (GLC 65 and PAR 68) and the Darlington Quiet Town Experiment Survey.

The student data were chosen to explore prediction matrix because they are a resource readily available at the Open University and because it would have required a large investment of time and effort to collect and analyse other sources of noise data.

6.2.3 Results from the Analysis of Variance Testing of the Prediction Matrix Using the Three Case Study Area Data

The results from the one-way analysis of variance of the noise indices L_{Aeq} , L_{A10} and L_{A90} across the eight area-type classifications are given in Tables 6.1 to 6.3.

The F-test results show that the null hypothesis can be rejected at the 1% confidence level for all of the noise indices.

The area-type classifications tested are therefore 99% certain to group 1 km² squares into area-types with significantly different levels of typical L_{Aeq} , L_{A10} and L_{A90} .

This result confirms the hypothesis that there is a significant relationship between the typical noise levels within a 1 km² square and the demographic characteristics of that 1 km² square as defined by the cells of the prediction matrix.

Table 6.1 Analysis of variance test of wind corrected L_{Aeq} by area-type classification - noise survey data.

Source of variance	Degrees of freedom	Sum of squares	Mean squares	F ratio	F probability
Between groups	7	278.3463	39.7638	3.8532	0.0038
Within groups	32	330.2290	10.3197		
Total	39	608.5753			

Table 6.2 Analysis of variance test of wind corrected L_{A10} by area-type classification - noise survey data.

Source of variance	Degrees of freedom	Sum of squares	Mean squares	F ratio	F probability
Between groups	7	256.7653	36.6808	3.7569	0.0044
Within groups	32	312.4370	9.7637		
Total	39	569.2023			

Table 6.3 Analysis of variance test of wind corrected L_{A90} by area-type classification - noise survey data.

Source of variance	Degrees of freedom	Sum of squares	Mean squares	F ratio	F probability
Between groups	7	439.9389	62.8484	5.9400	0.0002
Within groups	32	338.5787	10.5806		
Total	39	778.5176			

6.2.4 Results of the Analysis of Variance Testing of the Prediction Matrix Using the Student Data

Analysis of variance tests were performed on the six matrix cells calibrated with fifteen or more student measurements.

The variable used to describe the contribution to noise levels made by traffic is derived from the types of road within the 1 km² square surrounding the student's measurement site. The derivation of this variable is described in greater detail in Appendix B (Page 350). The road classification variable has a correlation coefficient of -0.6295 and a two-tailed significance of 0.0000 for the data from the three case study areas.

This inverse relationship is contrary to that which is hypothesised in Section B.2. This unexpected result may be due to the small number of 1 km² squares used to test the relationship and the limited range of traffic densities within these squares. Thus, despite the inverse relationship shown by the three case study area data the traffic density variable derived from the road classifications may still be a valid estimate of the traffic densities in the students sample 1 km² squares.

The noise index L_{A90} (wind corrected) was omitted from the analysis as the homogeneity of variance assumption underlying the analysis of variance technique is not satisfied by the data mainly due to the high standard deviation of the measurements in the 'residential/industrial - 2001-4000 vehicle density' category of 10.2 dB(A).

The results from the analysis of variance and subsequent F-tests on the L_{Aeq} and L_{A10} data are given in Tables 6.4 to 6.5.

The F-test results show that the null hypothesis can be rejected at the 5% confidence level for L_{Aeq} and at the 1% confidence level for L_{A10} . Despite the larger sources of error in the student data, the results for L_{Aeq} and L_{A10} seem to confirm the results from the analysis of the three case study area data. Matrix groups with different demographic characteristics have significantly different levels of noise.

Table 6.4 Analysis of variance test of wind corrected L_{Aeq} by area-type classification - student data.

Source of variance	Degrees of freedom	Sum of squares	Mean squares	F ratio	F probability
Between groups	5	1009.9327	201.9865	2.6185	0.0257
Within groups	195	15042.2019	77.1395		
Total	200	16052.1346			

Table 6.5 Analysis of variance test of wind corrected L_{A10} by area-type classification - student data.

Source of variance	Degrees of freedom	Sum of squares	Mean squares	F ratio	F probability
Between groups	5	1526.4110	305.2822	3.7323	0.0030
Within groups	199	16277.2852	81.7954		
Total	204	17803.6963			

6.2.5 Further Testing of the Prediction Matrix Structure

The results of these analyses of variances are further investigated to determine which pairs of matrix cells are significantly different at the 5% level and thus examine the explanatory power of the prediction model.

Test for Significantly Different Area-type Pairs Using the Scheffé test.

The Scheffé test (SCH 53) is used to compare each pair of area-type classifications, as defined by the prediction matrix and to test whether the average noise level of L_{Aeq} , L_{A10} and L_{A90} for these pairs are significantly different.

The Scheffé test procedure consists of the following steps:

1. An F ratio is computed for each pair of calibrated area-type classifications.
2. The 5% confidence value of F for $(k - 1)$ degrees of freedom is multiplied by $(k - 1)$ where k is the number of area-type classifications.
3. Each of the F ratios calculated in step 1 is compared with the value calculated in step 2. Area-type classification pairs whose F ratio is greater than the value from step 2 are judged significantly different at the 5% confidence level.

The Scheffé test is the most conservative test of the difference between pairs that is widely used.

The Scheffé results show that only a few pairs of area-types have significantly different levels of noise at the 5% confidence level.

Figures 6.1 and 6.2 show the significantly different pairs for the three case study area data analysis and the student data analysis respectively.

The results indicate that the majority of the calibrated area-type categories in the two axes are not significantly different from one another. However, despite this poor differentiation between noise levels in the two axes of the matrix, the analysis of variance results do suggest that there is a significant relationship between typical noise measure of L_{Aeq} , L_{A10} and L_{A90}

within a 1 km² square and the demographic classification of that 1 km² square. Further calibration of the model, especially the other cells of the matrix, would allow a full investigation of the model's ability to discriminate between area-types with significantly different noise levels.

Differentiation Between Noise Levels Along the Two Axes of the Prediction Matrix

Separate one-way analyses of variance test are performed on the individual axes of the prediction matrix using the data from the three case study areas (assumptions satisfied). The results show that the area-type classification in the 2001-4000 veh.km/hr/km² traffic-road density axis are not significantly different at the 5% confidence level for any of the noise indices. Whilst the area-type categories in the residential land use axis only have one pair of area-type classifications that are significantly different for L_{A90}.

We can conclude that for the 2001-4000 veh.km/hr/km² axis of the matrix the land use categories are poor differentiators between noise levels. This may be due to the dominance of noise due to traffic in these area-types. In areas, where there are lower traffic-road densities, land use may be more important as a variable that differentiates between noise levels. Indeed the student data have two significantly different land use pairs in the road-density category 1001-2000 veh.km/hr/km² axis of the matrix. Although it should be noted that the road density category for the student data can only be deduced very approximately.

The poor differentiation between area-types with different noise characteristics may be due to the restrictive nature of the area-type classifications and their somewhat arbitrary selection.

These results indicate that linear regression analysis of noise indices and land use data may be the preferred method for developing a model for predicting L_{Aeq}, L_{A10} and L_{A90} as such a model will be free from the area-type category restrictions where the predictor variables are continuous variables.

Figure 6.1 Significantly different pairs of area-type classifications - noise survey data

Land Use	Traffic Density (veh.km/hr/sq.km)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open Space					
Residential		• △			•
Commercial					
Industrial				△	
Residential/ Commercial					
Residential/ Industrial					
Commercial/ Industrial					
Residential/ Commercial/ Industrial					

Symbols denote significantly different pairs at the 5% confidence level

• = L_{A90}

△ = L_{Aeq} , L_{A10} and L_{A90}

= Not calibrated

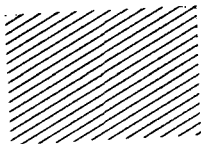


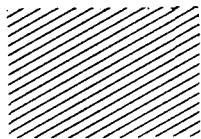
Figure 6.2 Significantly different pairs of area-type classifications -student data

Land Use	Traffic Density (veh.km/hr/sq.km)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open Space			◇		
Residential					
Commercial					
Industrial					
Residential/ Commercial					
Residential/ Industrial			◇		
Commercial/ Industrial					
Residential/ Commercial/ Industrial					

Symbols denote significantly different pairs at the 5% confidence level

◇ = L_{Aeq} and L_{A10}

= Not calibrated



6.2.6 Testing of General Hypothesis 1 Using Regression Analysis - Noise

The survey data from the three case study areas are used to explore the possibility of regression model prediction of area-based noise levels and to develop a model for predicting noise levels in those three regions.

The results from these statistical analyses may have implications for general noise levels throughout the United Kingdom. This will, however, depend upon the extent to which the regional data are representative of the noise and land use mixes found nationwide and whether there are regional differences in noise levels or in this relationship.

The 1 km² squares have been selected to test the theoretical prediction matrix and are not randomly selected and therefore not strictly representative sample of the wide span of land uses and noise levels nationwide.

The regression model developed for the three case study areas data will be tested using the national student data to determine whether this model is representative of the relationship between land use and noise levels found nationwide.

Assumptions Underlying the Regression Analysis Technique

To draw inferences about the dependent variable the following assumptions must be satisfied:

- Normality

For any fixed value of the independent variable(s), the distribution of the dependent variable is normal.

- Equality of variance

For any fixed value of the independent variable(s), the distribution of the dependent variable has a constant variance.

- Linearity

For all fixed values of the independent variable(s), the mean values of the distribution of the dependent variable all lie on a straight line which is the population regression line.

6.2.7 The Theoretical Regression Model

In Section 4.4.1 it is stated that two of the assumptions underlying the prediction of noise levels from land use and traffic density are that:

- there are a uniform distribution of sources and source strengths in the unit of land area for each of the predictor variables and
- that:

$$SWL = 10 \log\left(\frac{W_{ave.}}{W_0}\right)$$

where:

SWL is the sound power level in dB(A)

$W_{ave.}$ is the area average sound power of the sources
in watts

W_0 is the reference sound power in watts and therefore
a constant.

If it is assumed that sound pressure level (SPL) is independent of location within the 1 km² square, i.e. noise within the square is homogenous, then the equation for SWL can be used to derive the theoretical regression model structure for predicting L_{Aeq} , L_{A10} and L_{A90} by assuming SPL is proportional to SWL:

$$e^{\frac{SPL}{10}} = B_0 + B_1X_1 + B_2X_2 + + B_nX_n \quad (6.1)$$

where:

SPL represents the predicted L_{Aeq} , L_{A10} or L_{A90} values
between 10am. and 4pm.

B_0 is the equation constant

$B_1 - B_n$ are the coefficients of the variables

$X_1 - X_n$ are the demographic predictor variables.

This equation relates a measure of sound energy to the ‘percent land use’ and ‘traffic density’ regression variables and supports the hypothesis that noise levels are related to the type and degree of activity within an area.

All of these models are simple additive regression models using four independent demographic variables:

- Traffic density (veh.km/hr/km²)
- Industrial land use %
- Commercial land use %
- Residential land use %

Open space is omitted from the regression equation as there is a linear relationship between open space, and the other three land use categories, i.e. % open space = 100 - (% industry + % commerce + % residential). In the Milton Keynes and Bexley case study areas open space % is highly correlated with residential % as shown in Tables B.7 and B.8.

These models are free from the restrictions imposed by the somewhat arbitrary land use categories used in the prediction matrix and in previous regression models but do not allow for interaction between the variables.

The regression models are thus:

$$e^{\frac{L_{Aeq}}{10}} = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 \quad (6.2)$$

$$e^{\frac{L_{A10}}{10}} = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 \quad (6.3)$$

$$e^{\frac{L_{A90}}{10}} = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 \quad (6.4)$$

where:

B_0 is the equation constant

$B_1 - B_4$ are the variable coefficients

X_1 is the traffic-road density veh.km/hr/km²

X_2 is the percentage of industrial land use

X_3 is the percentage of commercial land use

X_4 is the percentage of residential land use

Table 6.6 Correlation coefficients between the noise indices and the demographic variables

	Percentage Open Space	Percentage Residential	Percentage Commercial	Percentage Industrial	Traffic Density
L_{Aeq}	-0.0065 (43) P=0.967	-0.2651 (43) P=0.086	-0.0132 (43) P=0.933	0.3941 (43) P=0.009	0.3196 (43) P=0.037
L_{A10}	-0.0046 (43) P=0.977	-0.2671 (43) P=0.083	0.0048 (43) P=0.976	0.3889 (43) P=0.010	0.3125 (43) P=0.041
L_{A90}	0.0541 (43) P=0.730	-0.3534 (43) P=0.020	0.1058 (43) P=0.500	0.3993 (43) P=0.008	0.5583 (43) P=0.000

(Pearson's correlation coefficient/(number of cases)/2-tailed significance)

6.2.8 Correlations Between the Un-transformed and Exponential Indices and the Demographic Variables

Tables 6.6 and 6.7 give the correlation coefficients for the relationship between demographic variables and the variables:

1. L_{Aeq} , L_{A10} and L_{A90} .
2. $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$.

along with the two-tailed significance of these correlations.

It can be seen that, where there are significant correlations, the $e^{\frac{SPL}{10}}$ variables have generally higher correlations with the demographic variables than the simple noise indices except for L_{A90} .

Table 6.7 Correlation coefficient between the exponential of the (noise indices)/10 and the demographic variables

	Percentage Open Space	Percentage Residential	Percentage Commercial	Percentage Industrial	Traffic Density
$e^{\frac{L_{Aeq}}{10}}$	-0.0116 ⁺ (43) P=0.941	-0.2884 ⁺ (43) P=0.061	-0.0325 ⁺ (43) P=0.836	0.4406* (43) P=0.003	0.3278 (43) P=0.032
$e^{\frac{L_{A10}}{10}}$	-0.0260 ⁺ (43) P=0.869	-0.2760 ⁺ (43) P=0.073	-0.0044 ⁺ (43) P=0.978	0.4347* (43) P=0.004	0.3262* (43) P=0.033
$e^{\frac{L_{A90}}{10}}$	0.0025 ⁺ (43) P=0.987	-0.3106 (43) P=0.043	0.1018 ⁺ (43) P=0.516	0.4122 (43) P=0.006	0.6020* (43) P=0.000

(Pearson's correlation coefficient/(number of cases)/2-tailed significance)

* Significant improvement in correlation coefficient.

+ Not tested using Hotelling's t-test as the un-transformed correlation coefficient is not significant at the 95% confidence level.

The Hotelling t-test statistical technique (HOL 40) is used to test whether the improvements in these correlation coefficient are significant. The Hotelling formula is:

$$t = \frac{r_{11} - r_{12}}{\sqrt{\frac{(N-3)(1+r_{23})}{2(1-r_{23}^2-r_{12}^2-r_{13}^2+2r_{23}r_{12}r_{13})}}}$$

Where:

- r_{11} is the correlation coefficient for the transformed variable
- r_{12} is the correlation coefficient for the un-transformed variable
- r_{23} is the correlation coefficient between the two sets of variables and
- N is the number of values

The results from Hotelling t-test show that all of the the transformed correlation coefficients in Table 6.7 which are marked with a '*' are significantly better than the un-transformed correlation coefficient at the 95% confidence level. The Hotelling t-test was only used to test those un-transformed correlation coefficients which are significant i.e. $P = 0.05$.

It can be seen that most of the significant correlations are significantly improved by transforming the data using the exponential function. This supports the assumptions made in Section 6.2.7 to derive the theoretical prediction models. However, the correlation between percentage residential land use and L_{A10} is significantly worsened by using the exponential transformation at the 95% confidence limit.

As expected the traffic-road density variable is highly correlated with the L_{A90} terms.

Industrial land use is significantly correlated with the L_{Aeq} and L_{A10} terms.

6.2.9 Results from the Regression Analysis of the Noise and Land Use Data from the Three Case Study Areas

The regression models results for the dependent variables $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ against the demographic variables (traffic-road density, and residen-

Table 6.8 Results of full regression analysis of $e^{\frac{L_{Aeq}}{10}}$ against the demographic variables

Multiple R	0.57124
R Square	0.32631
Adjusted R Square	0.25540
Standard Error	Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
Traffic-road density	0.028964	0.011353	0.353291	2.551	0.0149
%Residential land use	-0.613682	0.619546	-0.143838	-0.991	0.3282
%Commercial land use	-2.782696	2.827359	-0.136191	-0.984	0.3312
% Industrial land use	2.290206	0.890708	0.373581	2.571	0.0142
(Constant)	292.370322	47.713967		6.128	0.0000

tial, commercial and industrial land uses) are shown in Tables 6.8 to 6.10. B is the variable coefficient, Beta is the standard partial regression coefficient and t is the student's t value.

In the regression models for $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ the variables traffic-density and % industrial land use are the only variables that significantly contribute towards the performance of the models at the 5% confidence level.

The regression analyses were performed again but only including the demographic variables which make a significant contribution to explaining the variance in the noise levels at the 5% confidence limit. The results of these final regression analyses are given below in equation form (Equations 6.5 to 6.7). The letters 'I' and 'D' stand for the percentage of industrial land use and the traffic density within a 1 km² square respectively. The figures inside the brackets are the student's t values.

$$e^{\frac{L_{Aeq}}{10}} = 250.856014 + 2.634839I + 0.025650D \quad (6.5)$$

(7.398) (3.228) (2.350)

Table 6.9 Results of full regression analysis of $e^{\frac{L_{A10}}{10}}$ against the demographic variables

Multiple R 0.55727
R Square 0.31055
Adjusted R Square 0.23798
Standard Error Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
Traffic-road density	0.033064	0.013496	0.343218	2.450	0.0190
%Residential land use	-0.660017	0.736473	-0.131651	-0.896	0.3758
%Commercial land use	-2.527405	3.360969	-0.105267	-0.752	0.4567
% Industrial land use	2.681651	1.058812	0.372263	2.533	0.0156
(Constant)	350.045217	56.719071		6.172	0.0000

Table 6.10 Results of full regression analysis of $e^{\frac{L_{A90}}{10}}$ against the demographic variables

Multiple R 0.74236
R Square 0.55110
Adjusted R Square 0.50385
Standard Error Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
Traffic-road density	0.024642	0.004548	0.612476	5.418	0.0000
% Residential land use	-0.400215	0.248186	-0.191145	-1.613	0.1151
% Industrial land use	-0.718938	1.132624	-0.071699	-0.635	0.5294
% Commercial land use	0.951058	0.356812	0.316123	2.665	0.0112
(Constant)	91.654523	19.113948		4.795	0.0000

Multiple R	0.54031
R square	0.29193
Adjusted R square	0.25653
Standard error	Unknown

$$e^{\frac{L_{A10}}{10}} = 307.045796 + 3.053550I + 0.030008D \quad (6.6)$$

(7.673) (3.171) (2.330)

Multiple R	0.53465
R square	0.28586
Adjusted R square	0.25015
Standard error	Unknown

$$e^{\frac{L_{A90}}{10}} = 68.464383 + 1.178704I + 0.023676D \quad (6.7)$$

(4.975) (3.559) (5.345)

Multiple R	0.71816
R square	0.51576
Adjusted R square	0.49155
Standard error	Unknown

Conclusions

The variables, percentage of industrial land use and traffic density (veh. km/hr/km²), are important determinants of noise. However, residential and commercial land use percentages are not important determinants in the areas surveyed. The equations for $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ explain 25.7%, 28.6% and 49.0% of the variance in the noise levels respectively. The standard of estimates for these equations in terms of L_{Aeq} , L_{A10} and L_{A90} cannot be assessed using the normal method for calculating the standard error because the predicted values are exponential. Indeed this method produces estimates of the standard error of 46.3, 47.9 and 37.3 dB(A) for L_{Aeq} , L_{A10} and L_{A90} respectively ! The maximum standard deviation of any one group of measurements is 4.8 dB(A). The standard error of estimate

Table 6.11 Results of full regression analysis of $e^{\frac{L_{Aeq}}{10}}$ against the demographic variables - student data

Multiple R	0.26249
R Square	0.06890
Adjusted R Square	0.05264
Standard Error	Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
Traffic-road density	0.001808	0.016668	0.006996	0.108	0.9137
% Residential land use	1.364962	0.701131	0.125028	1.947	0.0528
% Industrial land use	9.760512	2.961994	0.212171	3.295	0.0011
% Commercial land use	4.125587	3.387212	0.079351	1.218	0.2245
(Constant)	139.607036	58.363572		2.392	0.0176

can be ascertained using the 'Monte Carlo' statistical technique but this is beyond the scope of the present study. The Monte Carlo method of risk assessment is discussed further in Section 8.3. Another alternative is to explore the use of polynomial regression analysis this is also discussed in Section 8.3.

6.2.10 Results from the Regression Analysis of the Student Noise Measurements and Demographic Data

The regression model results for the dependent variables $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ against the demographic variables: traffic density, and percentage residential, commercial, and industrial land uses; are shown in Tables 6.11 to 6.13.

In the regression equations for $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ only the industrial land use category makes a significant contribution to explaining the variations in noise levels at the 5% confidence level.

The regression analysis for the dependent variables $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ have been rerun but including only the industrial land use predictor

Table 6.12 Results of full regression analysis of $e^{\frac{L_{A10}}{10}}$ against the demographic variables - student data

Multiple R 0.26570
R Square 0.07060
Adjusted R Square 0.05471
Standard Error Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
Traffic-road density	0.007260	0.024795	0.018636	0.293	0.7699
% Residential land use	2.028696	1.059912	0.121490	1.914	0.0568
% Industrial land use	16.331325	4.520549	0.229943	3.613	0.0004
% Commercial land use	3.786524	5.150243	0.047304	0.735	0.4629
(Constant)	203.659954	87.074653		2.339	0.0202

Table 6.13 Results of full regression analysis of $e^{\frac{L_{A90}}{10}}$ against the demographic variables - student data

Multiple R 0.29639
R Square 0.08785
Adjusted R Square 0.07225
Standard Error Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
Traffic-road density	0.003659	0.005303	0.043512	0.690	0.4909
% Residential land use	0.301413	0.226666	0.083618	1.330	0.1849
% Industrial land use	4.034231	0.966735	0.263133	4.173	0.0000
% Commercial land use	1.266811	1.101397	0.073314	1.150	0.2512
(Constant)	51.688116	18.621215		2.776	0.0060

variable. The results from these regression analyses are given in equation form on Page 184.

$$e^{\frac{L_{Aeq}}{10}} = 235.136532 + 9.76553I$$

(11.571) (3.309)

Multiple R = 0.21228
R square = 0.04506
Adjusted R square = 0.4095
Standard error = Unknown

$$e^{\frac{L_{A10}}{10}} = 347.239425 + 16.182234I$$

(11.345) (3.602)

Multiple R = 0.22784
R square = 0.05191
Adjusted R square = 0.04791
Standard error = Unknown

$$e^{\frac{L_{A90}}{10}} = 81.439864 + 4.099833I$$

(12.456) (4.272)

Multiple R = 0.26741
R square = 0.07151
Adjusted R square = 0.06759
Standard error = Unknown

Conclusions

The regression equations for $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ derived from the student data on a national scale only use one predictor variable: percentage of industrial land use. The equations for $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ explain 4%, 5% and 7% of the variations in noise levels respectively. The calculated standard errors of estimation of these equations are not valid (see Page 182).

However, an indication of the standard error of estimate of these equations is given by the plots of the studentised residuals against region (Figures 6.4 to 6.6). The studentised residuals are for $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ values.

Table 6.14 Basic noise levels

	Data source	
	Three case study areas	Students
L_{Aeq}	55.2	54.6
L_{A10}	57.3	58.5
L_{A90}	42.3	44.0

Table 6.15 Maximum noise levels

	Data source	
	Three case study areas	Students
L_{Aeq}	65.8	71.0
L_{A10}	67.5	75.8
L_{A90}	59.3	62.0

Comparison of the two sets of regression models

The regression models derived from the three case study area data have two predictor variables: industrial land use and traffic density. The regression models derived from the student data also suggest that industrial land use is a predictor variable but the estimated traffic density predictor variable does not explain a significant proportion of the observed variance in the data examined.

Tables 6.14 and 6.15 compare the minimum (i.e. 0% industry and zero traffic) and maximum (i.e. 100% industrial land use and traffic density of 8000 veh.km./hr./km²) noise levels derived from each set of regression models.

Table 6.16 compares the predicted ambient L_{Aeq} , L_{A10} and L_{A90} for a 1 km² square which has a traffic density of 3000 veh. km/hr./km² and 20% industrial land use, predicted using the models derived from the three case study area data and the student data.

Table 6.16 Intermediate noise levels

	Data source	
	Three case study areas	Students
L_{Aeq}	59.4	60.6
L_{A10}	61.3	65.1
L_{A90}	50.9	51.0

It can be seen that the basic noise levels for the two sets of data are very similar. However, the maximum noise levels are considerably different. The student data have consistently higher maximum noise levels for each of the noise indices.

The discrepancies between the two sets of models may be attributable to:

1. the wider range of area-types sampled by the students and
2. inaccuracies in the students demographic data (especially the derivation of the traffic density variable).

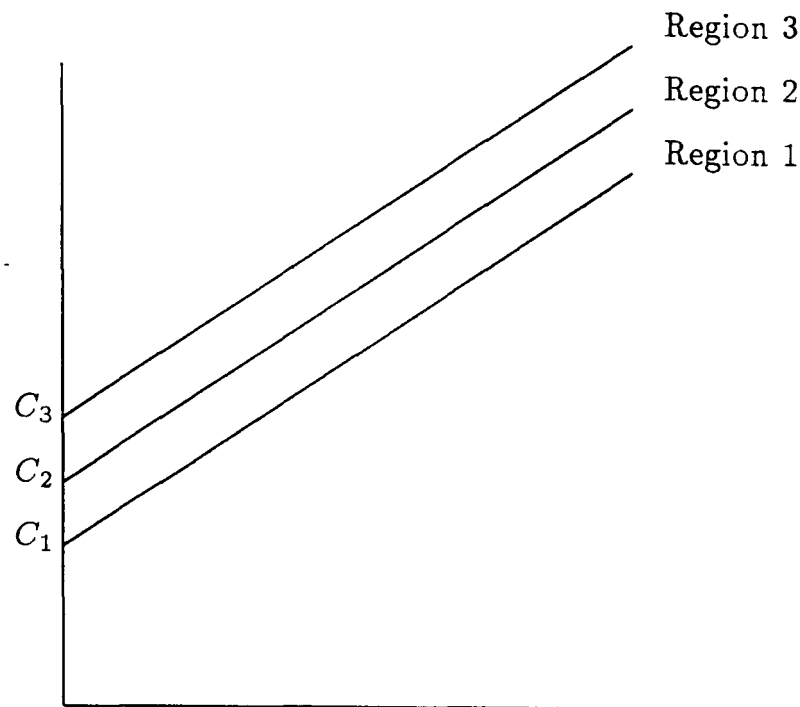


Figure 6.3 Two dimensional representation of 'parallel' regional models.

6.3 Testing of General Hypothesis 2 - Noise.

Regression analysis is used to investigate the hypothesis:

'that there are regional variations in noise levels unaccounted for by the demographic variables used in the proposed model.'

Firstly the data are tested to determine whether the data from the three regions can be represented by 'parallel' regression models.

This test can be represented in two dimensions by Figure 6.3.

Secondly the data are tested to determine whether the three regional sets of data can be represented by a single regression line without separate regional coefficients (i.e. in Figure 6.3 $C_1 = C_2 = C_3$). This analysis is carried out on both the three case study area data and on the student data.

6.3.1 Test for ‘Parallelism’ in the Regional Regression Models - Three Case Study Area Data

Two different regression models are computed for predicting each of the noise indices L_{Aeq} , L_{A10} , and L_{A90} . An F-test is performed on the residual sums of squares from each pair of regression models to determine whether the regional regression models are ‘parallel’.

Regional binary dummy variables are used in both sets of regression models.

The first set of regression models each have fifteen equation variables. These fifteen variables consist of the three regional binary dummy variables and the product of each of these variables with each of the four demographic variables used in the previous regression models. These regression models contain independent regression models for each of the case study areas.

The second set of regression equations each consist of three ‘parallel’ regression models for the demographic variables but contain separate regional constants. These models have seven equation variables and no common equation constant. The seven variables are the three regional binary dummy variables and the four demographic variables.

The results from the F-tests to determine whether the regional regression models are significantly ‘non-parallel’ are given in Table 6.17. The 5% confidence level for these degrees of freedom is 2.29.

These results show that that, for all the noise indices, there is no significant difference at the 5% confidence level between the ‘parallelism’ of the three regional models and that they can be considered ‘parallel’.

6.3.2 Test to Determine Whether the ‘Parallel’ Regional Models Have Significantly Different Constants - Three Case Study Area Data

An F-test is performed on the residual sums of squares from the original regression equations described in Section 6.2.9 and from the second set of

Table 6.17 Test for 'Parallel' Regional Models - three case study area data

Variable	F ratio	Degrees of freedom 1	Degrees of freedom 2
$e^{\frac{L_{Aeq}}{10}}$	1.6779	8	28
$e^{\frac{L_{A10}}{10}}$	1.4810	8	28
$e^{\frac{L_{A90}}{10}}$	2.1938	8	28

Table 6.18 Test for significantly different regional constants - three case study area data

Variable	F Ratio	Degrees of freedom 1	Degrees of freedom 2
$e^{\frac{L_{Aeq}}{10}}$	10.4153	2	36
$e^{\frac{L_{A10}}{10}}$	11.4840	2	36
$e^{\frac{L_{A90}}{10}}$	15.6502	2	36

regression equations computed in the test for parallelism of the regional models (Section 6.3.1).

The F-test, for each of the noise indices, tests whether there is a significant difference between the separate regional constants computed in the parallel regional model from Section 6.3.1.

The results from these F-tests are given in Table 6.18 (the 5% and 1% confidence levels are 3.26 and 5.26 respectively).

The results show there is a significant difference at the 1% level, between the regional model's constants for the three indices L_{Aeq} , L_{A10} and L_{A90} .

In summary, the data from the three case study areas have parallel regression models for each of the noise indices L_{Aeq} , L_{A10} and L_{A90} . However, the regional constants for the indices L_{Aeq} , L_{A10} and L_{A90} are significantly different at the 1% confidence level. Thus we can conclude that these data exhibit regional differences for L_{Aeq} , L_{A10} and L_{A90} that are not explained

by the demographic variables:

1. Traffic density
2. % Industrial land use
3. % Commercial land use
4. % Residential land use

The results from these regression analyses of the three case study area data suggests that there may be regional variations in noise levels generally throughout the United Kingdom that are not explained by the demographic variables used in the proposed regression model.

Regional variations in noise levels are further investigated using the student data, described in Appendix A, to determine whether this indication of regional variations from the non-randomly selected survey data is true generally for a wider range of area-types or whether it is peculiar to the three case study area data.

6.3.3 Results from the Regression Analysis of the Three Case Study Area Data with Regional Constants

Tables 6.19 to 6.21 summarise the results from the regression analyses described in Section 6.3.1 using the three case study area data.

It can be seen that for the regression models for the dependant variables $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ against the regional constants for the West Midlands and Milton Keynes, the traffic density variable and percentage industrial land use all contribute to the explanation of the variations in noise levels at or above the 5% confidence limit. The regional constant for Bexley can only be included at the 8.33% and 8.23% confidence level for $e^{\frac{L_{Aeq}}{10}}$ and $e^{\frac{L_{A10}}{10}}$ respectively and at the 24% confidence level for $e^{\frac{L_{A90}}{10}}$.

The regression models for $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ were re-run including all the regional constants but only including the land use predictor variable or traffic density variable where they make a contribution to the explanatory

Table 6.19 Results of full regression analysis of $e^{\frac{L_{Aeq}}{10}}$ against the demographic variables and regional constants - three case study area data

Multiple R	0.97788
R Square	0.95624
Adjusted R Square	0.94774
Standard Error	Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
West Midlands constant	268.055297	86.034000	0.386888	3.116	0.0036
Bexley constant	133.595140	74.995414	0.200693	1.781	0.0833
Milton Keynes constant	277.572256	45.432525	0.490662	6.110	0.0000
% Industrial land use	2.271876	0.999523	0.134936	2.273	0.0291
% Commercial land use	0.532143	2.638974	0.012591	0.202	0.8413
Traffic-road density	0.032070	0.009474	0.265760	3.385	0.0017
% Residential land use	0.055451	0.807755	0.008229	0.069	0.9456

Table 6.20 Results of full regression analysis of $e^{\frac{L_{A10}}{10}}$ against the demographic variables and regional constants - three case study area data

Multiple R	0.97926
R Square	0.95895
Adjusted R Square	0.95097
Standard Error	Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
West Midlands constant	321.631323	100.400659	0.385300	3.203	0.0028
Bexley constant	156.454616	87.518759	0.195079	1.788	0.0823
Milton Keynes constant	332.328102	53.019218	0.487588	6.268	0.0000
% Industrial land use	2.646826	1.166431	0.130481	2.269	0.0293
% Commercial land use	1.515703	3.079652	0.029767	0.492	0.6256
Traffic-road density	0.036838	0.011057	0.253380	3.332	0.0020
% Residential land use	0.148883	0.942640	0.018339	0.158	0.8754

Table 6.21 Results of full regression analysis of $e^{\frac{L_{A90}}{10}}$ against the demographic variables and regional constants - three case study area data

Multiple R	0.98334
R Square	0.96696
Adjusted R Square	0.96054
Standard Error	Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
West Midlands constant	98.449396	31.670660	0.335405	3.109	0.0037
Bexley constant	32.903193	27.607158	0.116674	1.192	0.2411
Milton Keynes constant	90.352223	16.724528	0.376999	5.402	0.0000
% Industrial land use	0.784472	0.367942	0.109980	2.132	0.0399
% Commercial land use	0.525684	0.971454	0.029360	0.541	0.5918
Traffic-road density	0.025626	0.003488	0.501276	7.7348	0.0000
% Residential land use	-0.241733	0.297349	-0.84680	-0.813	0.4216

power of the model at the 5% confidence level. The results from these regression models are given below.

$$e^{\frac{L_{Aeq}}{10}} = 257.754771W + 141.148953B + 280.984232M + 2.219974I + 0.032342D$$

(7.190) (4.000) (9.920) (3.196)

(3.614)

Multiple R = 0.97785
R square = 0.95619
Adjusted R square = 0.95043
Standard error = Unknown

$$e^{\frac{L_{A10}}{10}} = 342.773429W + 177.329745B + 341.683260M + 2.506759I + 0.037635D$$

(7.638) (4.295) (10.308) (3.084)

(3.594)

Multiple R = 0.97912
R square = 0.95867
Adjusted R square = 0.95323
Standard error = Unknown

$$e^{\frac{L_{A90}}{10}} = 68.186976W + 73.047707M + 1.039443I + 0.030364D$$

(5.694) (8.204) (3.968) (13.643)

Multiple R = 0.98168
R square = 0.96370
Adjusted R square = 0.95997
Standard error = Unknown

Although the standard errors of estimate are not quantified they will be less than those indicated for the previous regression models which are without regional constants. An indication of the standard error of estimate for these equations is given by the maps displaying the studentised residuals for $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ values (Figures 6.7 to 6.15). Methods for determining the true standard errors are discussed in Section 8.3.

Table 6.22 Basic noise levels in each of the three case study areas

Region	L_{Aeq}	L_{A10}	L_{A90}
Milton Keynes	56.4	58.3	42.9
Bexley	49.5	51.8	-
West Midlands	55.5	58.4	42.2

6.3.4 Demographic Predictor Variables That May Account for the Different Regional Constants

The results show that there are regional variations in the basic noise level¹ in the area-types tested. Table 6.22 compares the basic noise levels in each of the three case study areas.

It can be seen that the Milton Keynes and West Midland regions have similar basic noise levels for all three noise indices. The Bexley area has a significantly lower basic noise level. The three regions are all of contrasting types. It is perhaps surprising that the West Midlands and Milton Keynes are the regions that have such similar basic noise levels when they are the most different area-types. The reason for this apparent difference in regional noise levels may be due to:

1. sequential surveillance of the case study areas,
2. vehicle composition of traffic,
3. vehicle speed,
4. age structure of population and/or
5. daytime population density.

There are no major regional differences in topography between the three case study areas.

¹The basic noise level is the remaining noise level that exists when all the additional noise due to variations in demographic variable is removed

Temporal variations in noise levels may account for the differences in noise levels between the regional groups of data, as the three case study areas were surveyed sequentially between 24th. April 1986 and 17th. October 1986 (see Figure 5.1). In particular, the West Midlands case study area was surveyed during the school summer holidays and at a time when some industries have their summer shut down. However, monthly temporal variations in noise cannot be conclusively proven or disproved either by the existing research or by previous research (see Section 4.6.1).

If the differences in the regional constants are due to regional differences rather than temporal differences in noise levels this suggests that the accuracy of the noise models developed by Pocock (POC 79) could not be expected if applying these models to other regions. The following analysis of the student data further explores regional differences in noise levels.

6.3.5 Test for Regional Variances in Noise Levels (Student Data)

Data collected from the Open University students studying the course T234 'Environmental Control and Public Health' were used to further test the hypothesis that there are regional differences in noise levels.

An indication of whether there are any regional variations in the noise levels that are not explained by the student regression models can be seen from the plots in Figures 6.4 to 6.6 of the Studentised residuals² from the regression equations presented in Tables 6.11 and 6.13 against region.

The numerical and letter symbols used to represent the number of values at a point are given overleaf:

²A Studentised residual is a residual divided by the estimate of its standard deviation that varies from point to point depending upon the distance X_i from the mean \bar{X} . It reflects the difference in the true error from point to point.

1 - 1	11 - B	21 - L	31 - V
2 - 2	12 - C	22 - M	32 - W
3 - 3	13 - D	23 - N	33 - X
4 - 4	14 - E	24 - O	34 - Y
5 - 5	15 - F	25 - P	35 - Z
6 - 6	16 - G	26 - Q	36 - *
7 - 7	17 - H	27 - R	
8 - 8	18 - I	28 - S	
9 - 9	19 - J	29 - T	
10 - A	20 - K	30 - U	

The regional symbols are:

1 \equiv Scotland

2 \equiv Northern Ireland

3 \equiv North East

4 \equiv North West

5 \equiv Wales

6 \equiv Midlands

7 \equiv East Anglia

8 \equiv South West

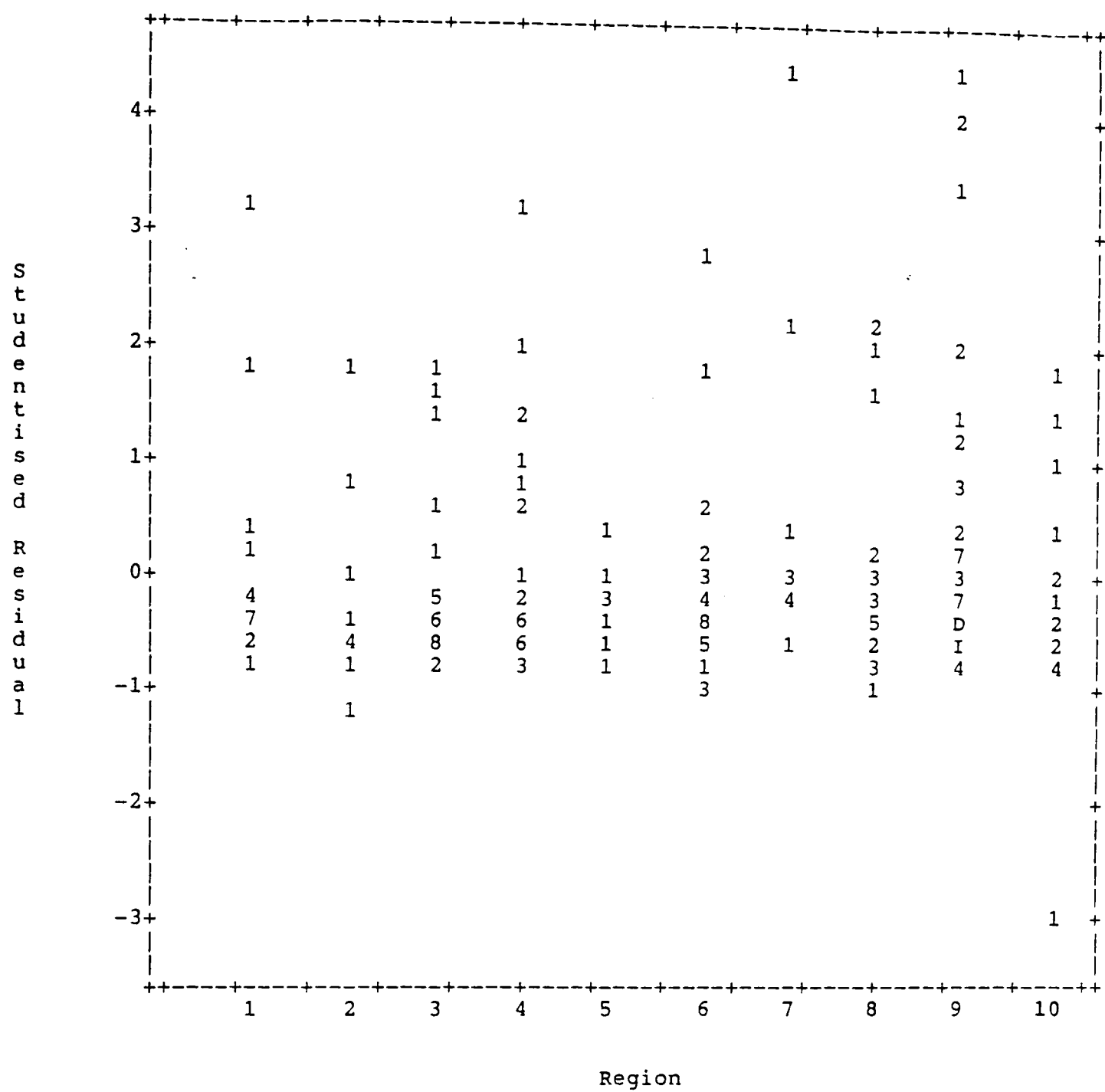
9 \equiv South East

10 \equiv London

In general there does not seem to be any marked difference in the regional noise levels L_{Aeq} , L_{A10} and L_{A90} . It can also be seen that the normality assumption for the regional analysis of the student data is not wholly satisfied by the regional groups of data.

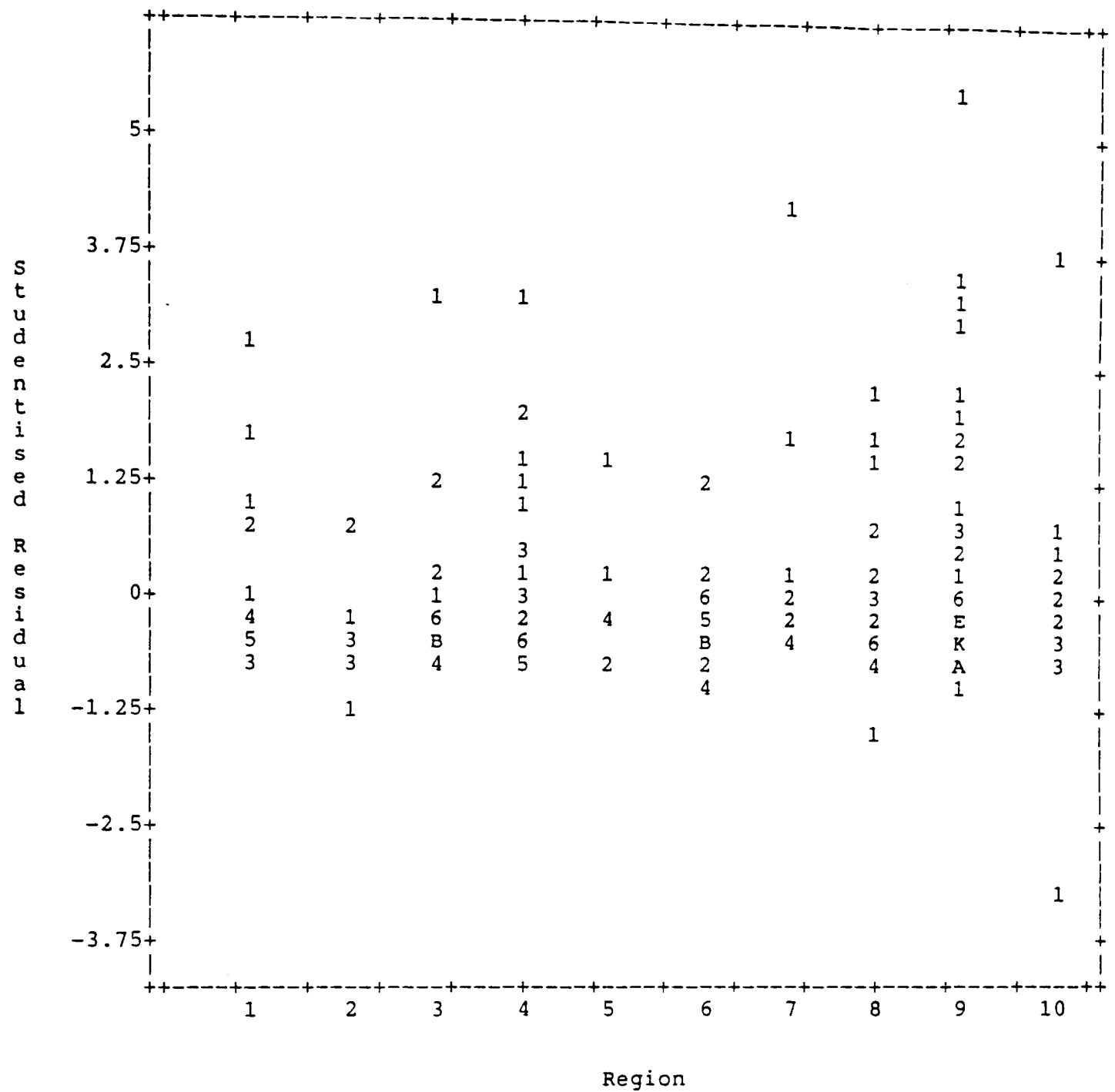
The tests for regional variations in noise levels using the student data are performed using data from the regions defined in Figure 3.7.

The number of measurements taken in each of these regions are shown in Figures A.6 and A.7. The small number of measurements in each of the regions may result in inaccurate results in the following analyses.



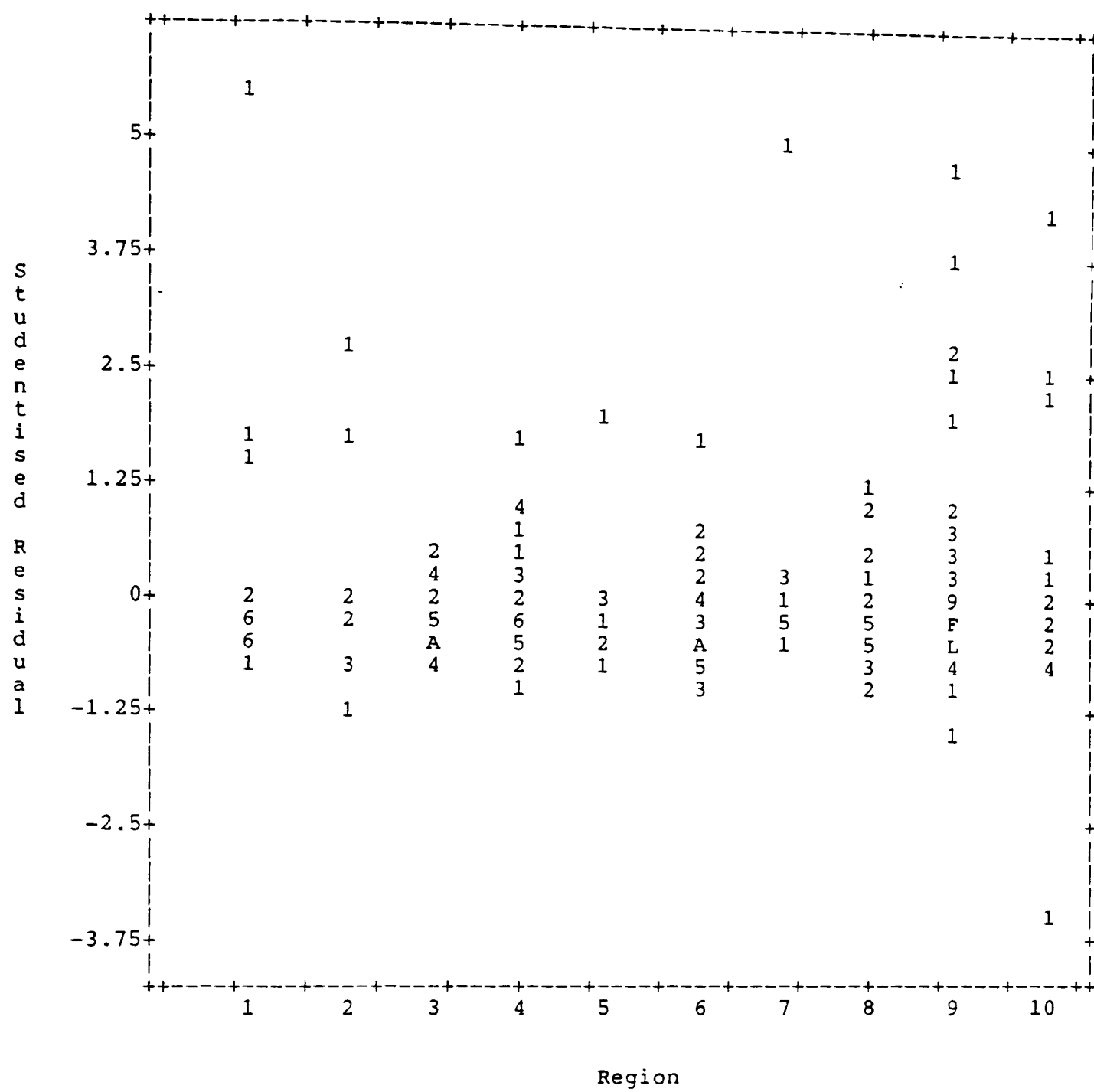
See Page 196 for region and 'number of values at a point' codes.

Figure 6.4 Studentised residuals for the full L_{Aeq} regression model plotted against region



See Page 196 for region and 'number of values at a point' codes.

Figure 6.5 Studentised residuals for the full L_{A10} regression model plotted against region



See Page 196 for region and 'number of values at a point' codes.

Figure 6.6 Studentised residuals for the full L_{A90} regression model plotted against region

Table 6.23 Test for ‘parallel’ regional models - student data

Variable	F ratio	Degrees of freedom 1	Degrees of freedom 2
$\frac{L_{Aeq}}{e \frac{10}{10}}$	1.6310	36	184
$\frac{L_{A10}}{e \frac{10}{10}}$	1.4500	36	189
$\frac{L_{A90}}{e \frac{10}{10}}$	1.4109	36	189

6.3.6 Results from the Test for ‘Parallelism’ of the Regional Models - Student Data

The test for parallelism of the regional models using the student data is performed using the statistical technique described in Section 6.3.1.

The results from the F-test to determine whether the two sets of regression models are significantly non-parallel are given in Table 6.23.

The 5% confidence level for 36/184 and 36/189 degrees of freedom are approximately 1.45. The results show that, for L_{A10} and L_{A90} , there is no significant difference in the parallelism of the sets of regression models at the 5% confidence level and thus the regional regression models are either parallel or concordant. However, the results for L_{Aeq} indicate that the regional models are significantly ‘non parallel’ at the 5% confidence level.

6.3.7 Test to Determine Whether the Parallel Regional Models are Concordant - Student Data

The regression models for L_{A10} and L_{A90} are tested to determine whether the regional models have significantly different constants. The statistical technique used to determine whether the regional models for L_{A10} and L_{A90} are concordant is described in Section 6.3.2. The results from this analysis is given in Table 6.24.

The 5% confidence level for these degrees of freedom is approximately 1.92. The results show that there is no significant difference between the

Table 6.24 Test for significantly different regional constants - student data

Variable	F ratio	Degrees of freedom 1	Degrees of freedom 2
$e \frac{L_{A10}}{10}$	1.2731	9	225
$e \frac{L_{A90}}{10}$	1.7269	9	225

regional constants at the 5% confidence level. This means that the regional regression models for both L_{A10} and L_{A90} can be considered coincident.

The regional regression models for L_{Aeq} are given below. Only those predictor variables which make a significant contribution to explaining the regional variations in L_{Aeq} noise levels are included.

$$e \frac{L_{Aeq}}{10} = R_1(4.96A) + R_2(4.48A) + R_3 \times 270.25 + R_4(28.70B + 228.90) + R_5(93.50C) + R_6 \times 197.33 \quad (6.8)$$

Where:

- R_1 = South West regional dummy variable
- R_2 = Scottish regional dummy variable
- R_3 = North West regional dummy variable
- R_4 = South East regional dummy variable
- R_5 = East Anglian regional dummy variable
- R_6 = Northern Irish regional dummy variable
- A = % Residential land use
- B = % Industrial land use
- C = % Commercial land use

Conclusions

The results from the testing of General Hypothesis 2 for the student measurements of L_{Aeq} , L_{A10} and L_{A90} taken between 6pm. and 10pm. throughout the United Kingdom show that:

- the regional classifications do not differentiate between groups of L_{A10} and groups of L_{A90} noise levels at the 5% confidence level.
- the regional classifications do differentiate between groups of L_{Aeq} noise levels at the 5% confidence level.

The students provide data from the regions which are sampled in a temporally random manner over a period of approximately one month. The results, although for a different daytime period (i.e. 6pm. to 10pm. rather than 10am. to 4pm.), suggests that the differences in noise levels identified by the regional classifications of the three case study area data may be due to the sequential sampling method used.

The results for L_{A10} and L_{A90} contrast with Ward's findings (WAR 88). Ward analysed the student data gathered from 1985 to 1987. Ward's work suggests that the only significant regional differences in the noise levels L_{Aeq} , L_{A10} and L_{A90} are between Scotland and the South East out of the following regional classifications:

- North
- Scotland
- Northern Ireland
- West Midlands
- East Midlands
- Yorkshire and Humberside
- East Anglia
- South West
- North West
- Wales
- South East

Scotland was found to be significantly quieter than the South East. However, Ward does not take into consideration the variations in noise levels that can be explained by the underlying demographic characteristics.

6.4 Testing of General Hypothesis 3 - Noise

‘That there is a relationship between different noise indices and that relationship will vary according to the area classifications.’

This hypothesis is investigated and tested by:

- examining the correlations between the different noise indices,
- examining the correlations between noise indices calculated using the methods reviewed in Section 3.1.1,
- averaging the difference between the noise indices,
- developing univariate and multivariate regression models based on the structure of previous prediction models³ and
- examining in detail whether the variations in the variable $L_{A10} - L_{A90}$ vary between different area-types or regions.

6.4.1 Correlations Between Wind Corrected Noise Indices in the Two Noise Surveys

Tables 6.25 and 6.26 give the Pearson correlation coefficient and two-tailed significance of the correlations between the area average and individual measurements of the noise indices measured in the three case study areas. Tables 6.27 and 6.28 give the Pearson’s correlation coefficients and two tailed significance for the correlations between:

- all the noise indices measured by the students and
- the noise indices measured by the students where the L_{Aeq} and the 100 spot readings of sound pressure level are taken during the same time period.

³Pocock’s relationship between L_{Aeq} and the UNL and LNL indices (POC 79) is not investigated as this relationship is theoretically derived rather than by analysis of measurements

Table 6.25 Correlations between noise indices - three case study areas (area averages).

	L_{Aeq}	L_{A10}	L_{A90}	$L_{A10} - L_{A90}$
L_{Aeq}	1.0000 (43) P=0.000	0.9915 (43) P=0.000	0.8678 (43) P=0.000	-0.0582 (43) P=0.000
L_{A10}	0.9915 (43) P=0.000	1.0000 (43) P=0.000	0.8660 (43) P=0.000	-0.0402 (43) P=0.798
L_{A90}	0.8678 (43) P=0.000	0.8660 (43) P=0.000	1.0000 (43) P=0.000	-0.5345 (43) P=0.000
$L_{A10} - L_{A90}$	-0.0582 (43) P=0.711	-0.0402 (43) P=0.796	-0.5345 (43) P=0.000	1.0000 (43) P=0.000

(Pearson's correlation coefficient/(number of cases)/2-tailed significance)

Table 6.26 Correlations between noise indices - three case study areas (individual measurements).

	L_{Aeq}	L_{A10}	L_{A90}	$L_{A10} - L_{A90}$
L_{Aeq}	1.0000 (1075) P=0.000	0.9714 (1075) P=0.000	0.7756 (1075) P=0.000	0.4039 (1075) P=0.000
L_{A10}	0.9714 (1075) P=0.000	1.0000 (1075) P=0.000	0.7639 (1075) P=0.000	0.4338 (1075) P=0.798
L_{A90}	0.7756 (1075) P=0.000	0.7639 (1075) P=0.000	1.0000 (1075) P=0.000	-0.0654 (1075) P=0.000
$L_{A10} - L_{A90}$	0.4039 (1075) P=0.711	0.4338 (1075) P=0.796	-0.0654 (1075) P=0.000	1.0000 (1075) P=0.000

(Pearson's correlation coefficient/(number of cases)/2-tailed significance)

Table 6.27 Correlations between noise indices - all student data

	Wind Corrected			
	L_{Aeq}	L_{A10}	L_{A90}	$L_{A10} - L_{A90}$
L_{Aeq}	1.0000 (407) P=0.000	0.9053 (407) P=0.000	0.7757 (407) P=0.000	0.4169 (407) P=0.000
L_{A10}	0.9053 (407) P=0.000	1.0000 (416) P=0.000	0.7637 (416) P=0.000	0.5807 (416) P=0.000
L_{A90}	0.7757 (407) P=0.000	0.7637 (416) P=0.000	1.0000 (416) P=0.000	-0.0819 (416) P=0.095
$L_{A10} - L_{A90}$	0.4189 (407) P=0.000	0.5889 (416) P=0.000	-0.0819 (416) P=0.095	1.0000 (416) P=0.000

(Pearson's correlation coefficient/(number of cases)/2-tailed significance)

As expected the noise data from both of the surveys show a high correlation between the L_{Aeq} and L_{A10} measures. There is also a lesser correlation between the L_{A90} and L_{A10} or L_{Aeq} indices, although all of the correlations are significant at the 99.95% confidence limit. There is no significant correlation between the $(L_{A10} - L_{A90})$ variable and each of the noise indices: L_{Aeq} , L_{A10} and L_{A90} for the area averaged values. However, the student data indicated a significant correlation between $(L_{A10} - L_{A90})$ and the L_{Aeq} and L_{A10} indices.

Table 6.28 Correlations between noise indices - student data where L_{Aeq} and the 100 spot readings are taken over the same time period

	Wind Corrected			
	L_{Aeq}	L_{A10}	L_{A90}	$L_{A10} - L_{A90}$
L_{Aeq}	1.0000 (240) P=0.000	0.9431 (240) P=0.000	0.7921 (240) P=0.000	0.3173 (240) P=0.000
L_{A10}	0.9431 (240) P=0.000	1.0000 (242) P=0.000	0.7186 (242) P=0.000	0.4305 (242) P=0.000
L_{A90}	0.7921 (240) P=0.000	0.7186 (242) P=0.000	1.0000 (242) P=0.000	-0.0725 (242) P=0.261
$L_{A10} - L_{A90}$	0.3173 (240) P=0.000	0.4305 (242) P=0.000	-0.0725 (242) P=0.261	1.0000 (242) P=0.000

(Pearson's correlation coefficient/(number of cases)/2-tailed significance)

6.4.2 Correlations Between Calculated and Measured Noise Indices

Tables 6.29 and 6.30 give the Pearson correlation coefficients and their significance for the relationship between the true L_{Aeq} and the L_{Aeq} calculated from the equations developed by Driscoll, Berry, the National Physics Laboratory and Pocock for the three case study areas survey and the student survey respectively.

The best correlation between the calculated and measured L_{Aeq} is for the area averaged L_{Aeq} calculated from the area average L_{A10} and L_{A90} (three case study area data). The correlations are also high for the non area averaged data from the three case study areas.

The correlations for the student data are lower than those for the three case study area data. This may be due to the the student L_{A10} and L_{A90} values being estimated from 100 spot readings of sound pressure level rather than from direct statistical measurement.

As expected the correlations between the students measurements of L_{Aeq} and the calculated L_{Aeq} are highest where the 100 spot readings are taken over the same time period as the L_{Aeq} measurement.

In all cases the simple models given by Driscoll, Berry and Borruso, derived from averaging the difference between the L_{A10} and L_{Aeq} values, produced the best Pearson's correlation coefficients for the relationship between calculated and measured L_{Aeq} .

It is interesting to note that Pocock's equation for calculating L_{Aeq} and measured L_{Aeq} from the Upper Noise Limit⁴ and the Lower Noise Limit⁵ has much lower Pearson correlation coefficients than the other calculation methods. It is particularly interesting that the correlation coefficient for the individual measurement locations is better than that for the area averaged values in the three case study areas.

⁴Approximates to L_{A10}

⁵Approximates to L_{A90}

Table 6.29 Correlations between the True L_{Aeq} and Calculated L_{Aeq} from Models Developed by Previous Researchers (Wind Corrected Data) - three case study area data

Model Formula	True L_{Aeq} (area averages)	True L_{Aeq} (single locations)
$L_{Aeq} = L_{A10} - 3.6$ (DR1 74)	0.9915 (43) P = 0.000	0.9704 (1075) P = 0.000
$L_{Aeq} = L_{A10} - 2.7$ (BER 76)	0.9915 (43) P = 0.000	0.9704 (1075) P = 0.000
$L_{Aeq} = L_{A10} - 2.9$ (BOR 79)	0.9915 (43) P = 0.000	0.9704 (1075) P = 0.000
$L_{Aeq} = L_{A90} + 6.2$ (BOR 79)	0.8678 (43) P = 0.000	0.7813 (1075) P = 0.000
$L_{Aeq} = (L_{A10} + L_{A90})/2$ $+ (L_{A10} - L_{A90})^2/57$ (BOR 79)	0.9905 (43) P = 0.000	0.9683 (1075) P = 0.000
Pocock's equation * (POC 79)	-0.0596 (43) P = 0.704	0.5125 (1075) P = 0.000

(Pearson's correlation coefficient/(number of cases)/2-tailed significance)

* Pocock's equation for calculating L_{Aeq} is given in Section 3.1.1.

Table 6.30 Correlations between the True L_{Aeq} and Calculated L_{Aeq} from Models Developed by Previous Researchers (Wind Corrected Data) - student data

Model Formula	True L_{Aeq} (single locations)	True L_{Aeq}^+ (single locations)
$L_{Aeq} = L_{A10} - 3.6$ (DR1 74)	0.9053 (407) P = 0.000	0.9322 (240) P = 0.000
$L_{Aeq} = L_{A10} - 2.7$ (BER 76)	0.9053 (407) P = 0.000	0.9322 (240) P = 0.000
$L_{Aeq} = L_{A10} - 2.9$ (BOR 79)	0.9053 (407) P = 0.000	0.9322 (240) P = 0.000
$L_{Aeq} = L_{A90} + 6.2$ (BOR 79)	0.7757 (407) P = 0.000	0.8360 (240) P = 0.000
$L_{Aeq} = (L_{A10} + L_{A90})/2$ $+ (L_{A10} - L_{A90})^2/57$ (BOR 79)	0.8990 (407) P = 0.000	0.9261 (240) P = 0.000
Pocock's equation * (POC 79)	0.3910 (407) P = 0.000	0.4163 (240) P = 0.000

(Pearson's correlation coefficient/(number of cases)/2-tailed significance)

* Pocock's equation for calculating L_{Aeq} is given in Section 3.1.1.

+ Includes only the measurements where L_{Aeq} is measured during the same period as the 100 spot readings.

Derived Relationships Between the Noise Indices

The noise data from the three case study areas and the student data have been used to derive methods for calculating L_{Aeq} , L_{A10} and L_{A90} noise levels for the periods 10am. to 4pm and 6pm. to 10pm. respectively. The calculation methods are based on the prediction methods discussed in Section 3.1.1.

The student data used to derive the following relationships between the noise indices are less rigorous than those from the three case study areas. The main differences are that the L_{A10} and L_{A90} values are calculated from 100 spot readings and that the L_{Aeq} measurement is not always taken at the same time as the spot readings used to calculate the L_{A10} and L_{A90} values.

Two methods for deriving calculation methods were used:

1. simple averaging of the difference between noise indices,
2. univariate regression analysis and
3. multivariate regression analysis.

The first approach is far less rigorous than the second and third approaches which both apply a 'best fit' line to the data. The first method was used by Berry (BER 74), Driscoll (DRI 74) and Borruso *et al.* (BOR 79) and has been included for comparison sake. The relationships derived using each of these techniques are set out in the next three sections.

Average Difference Between Noise indices

The sets of models derived using the average difference between noise indices are shown below. The student models for predicting L_{Aeq} are derived from only those sets of data where the L_{Aeq} measurement is taken during the same period as the 100 spot readings were taken.

- Three Case Study Area Models - area averages

$$L_{Aeq} = L_{A10} - 1.9$$

$$\text{Standard deviation} = 0.5062$$

$$N = 43$$

$$L_{Aeq} = L_{A90} + 9.0$$

$$\text{Standard deviation} = 2.1788$$

$$N = 43$$

$$L_{A10} = L_{A90} + 10.9$$

$$\text{Standard deviation} = 2.1940$$

$$N = 43$$

- Three Case Study Area Models - individual measurements

$$L_{Aeq} = L_{A10} - 1.946$$

$$\text{Standard deviation} = 2.204$$

$$N = 1075$$

$$L_{Aeq} = L_{A90} + 9.088$$

$$\text{Standard deviation} = 5.539$$

$$N = 1075$$

$$L_{A10} = L_{A90} + 11.035$$

$$\text{Standard deviation} = 5.688$$

$$N = 1075$$

- Student Data Models (L_{A10} and L_{A90} derived from 100 spot readings)

$$L_{Aeq} = L_{A10} - 3.678$$

$$\text{Standard deviation} = 3.610$$

$$N = 240$$

$$L_{Aeq} = L_{A90} + 8.618$$

$$\text{Standard deviation} = 5.171$$

$$N = 240$$

$$L_{A10} = L_{A90} + 12.414$$

$$\text{Standard deviation} = 5.778$$

$$N = 242$$

Univariate Regression Analysis

The models derived using univariate regression analysis are shown below:

- Three Case Study Area Models - area averages

$$L_{Aeq} = L_{A10} - 3.4$$

$$\text{Standard error} = 0.5$$

$$N = 43$$

$$L_{Aeq} = \frac{L_{A90}}{1.3} + 20.8$$

$$\text{Standard error} = 1.9$$

$$N = 43$$

$$L_{A10} = \frac{L_{A90}}{1.3} + 24.0$$

$$\text{Standard error} = 1.9$$

$$N = 43$$

- Three Case Study Area Models - individual measurements

$$L_{Aeq} = \frac{L_{A10}}{1.1} + 1.9$$

$$\text{Standard error} = 2.1$$

$$N = 1075$$

$$L_{Aeq} = \frac{L_{A90}}{1.1} + 13.8$$

$$\text{Standard error} = 5.5$$

$$N = 1075$$

$$L_{A10} = \frac{L_{A90}}{1.1} + 14.0$$

$$\text{Standard error} = 5.7$$

$$N = 1075$$

- Student Data Models (L_{A10} and L_{A90} derived from 100 spot readings)

$$L_{Aeq} = \frac{L_{A10}}{1.1} + 3.1$$

$$\text{Standard error} = 3.4$$

$$N = 240$$

$$L_{Aeq} = \frac{L_{A90}}{1.1} + 11.0$$

$$\text{Standard error} = 5.2$$

$$N = 240$$

$$L_{A10} = L_{A90} + 13.1$$

$$\text{Standard error} = 5.8$$

$$N = 242$$

Multivariate Regression Analysis

- Three Case Study Area Models - area averages

$$L_{Aeq} = \frac{(L_{A10} + L_{A90})}{2} + \frac{(L_{A10} - L_{A90})^2}{48.7}$$

$$\text{Standard error} = 0.5$$

$$N = 43$$

- Three Case Study Area Models - individual measurements

$$L_{Aeq} = \frac{(L_{A10} + L_{A90})}{2} + \frac{(L_{A10} - L_{A90})^2}{69.4}$$

$$\text{Standard error} = 2.2$$

$$N = 1075$$

- Student Data Models (L_{A10} and L_{A90} derived from 100 spot readings)

$$L_{Aeq} = \frac{(L_{A10} + L_{A90})}{2} + \frac{(L_{A10} - L_{A90})^2}{148.0}$$

$$\text{Standard error} = 3.3$$

$$N = 240$$

6.4.3 Test to determine whether the relationship between the noise indices is a function of the area-type

The hypothesis that the relationship between variables is a function of area-type is tested using the variable $(L_{A10} - L_{A90})$. This variable is of considerable interest as it represents the variability in noise levels or noise climate

Table 6.31 Analysis of variance test of wind corrected (L_{A10} - L_{A90}) by area-type classification - three case study area data.

Source of variance	Degrees of freedom	Sum of squares	Mean squares	F ratio	F probability
Between groups	7	78.5846	11.2264	3.0728	0.0136
Within groups	32	116.9127	3.6535		
Total	39	195.4974			

Table 6.32 Analysis of variance test of wind corrected (L_{A10} - L_{A90}) by area-type classification - student data.

Source of variance	Degrees of freedom	Sum of squares	Mean squares	F ratio	F probability
Between groups	5	384.9878	76.9976	2.0409	0.0745
Within groups	199	7507.8715	37.7280		
Total	204	7892.8593			

which has been linked with public annoyance (GRI 68). However, subsequent research has not confirmed this result.

A one-way analysis of variance test is carried out on the prediction matrix calibrated with the (L_{A10} - L_{A90}) values (see Table 5.13). The test is carried out on the data from the three case study areas and on the student data. The results are given in Tables 6.31 and 6.32.

The results from the testing of the data from the three case study areas show that the null hypothesis 'there is no significant difference between the arithmetic means of the (L_{A10} - L_{A90}) values representing the different area-type classifications' can be rejected at the 1% confidence level.

However, in the analysis of the student data the null hypothesis cannot be rejected even at the 5% confidence level for the variable. The results from the analysis of variance test for the students (L_{A10} - L_{A90}) data do not confirm the results from the analysis of the three case study area data, although

the confidence level of the F-test is 7%, only 2% below the level chosen as the appropriate confidence threshold above which the null hypothesis is rejected (5%). This discrepancy between the two studies may be due to the large sources of error in the representativeness of the student data and the classification basis used with these data.

The one-way analysis of variance tests indicate that the variability in noise levels ($L_{A10} - L_{A90}$) may be significantly different in the area-types surveyed in the three case study areas. A Scheffé test was carried out on these data and one pair of significantly different area-types were identified:

1. Residential - 501 to 1000 veh.km/hr/km²
2. Residential - 4001 to 8000 veh.km/hr/km²

Regression analysis was used to further investigate the likely relationship between the variability of noise and area-type classification using Equation 6.9.

$$(L_{A10} - L_{A90}) = B_0 + B_1X_1 + B_2X_2 + \dots + B_nX_n \quad (6.9)$$

The theoretical multivariate regression models used in the investigation of L_{Aeq} , L_{A10} and L_{A90} are based on the relationship between sound power level and sound pressure level. The variable $L_{A10} - L_{A90}$ represents the variability in noise levels and, therefore, the relationship is tested using the following equation:

$$(L_{A10} - L_{A90}) = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 \quad (6.10)$$

where:

B_0 is the equation constant

$B_1 - B_4$ are the variable coefficients

X_1 is the traffic-road density veh.km/hr/km²

X_2 is the percentage of industrial land use

X_3 is the percentage of commercial land use

X_4 is the percentage of residential land use

Table 6.33 Correlation coefficients between ($L_{A10} - L_{A90}$) and the demographic variables

	Percentage Open Space	Percentage Residential	Percentage Commercial	Percentage Industrial	Traffic Density
$L_{A10} - L_{A90}$ (3 case study area data)	-0.1157 (43) P=0.460	0.2543 (43) P=0.100	-0.2031 (43) P=0.191	-0.1401 (43) P=0.370	-0.5873 (43) P=0.000
$L_{A10} - L_{A90}$ (Student data)	-0.0879 (239) P=0.176	0.0883 (239) P=0.174	0.0247 (239) P=0.704	-0.0027 (239) P=0.967	-0.0769 (239) P=0.236

(Pearson's correlation coefficient/(number of cases)/2-tailed significance)

Table 6.33 gives the Pearson correlation coefficients and two-tailed significance for the relationships between the ($L_{A10} - L_{A90}$) variable and the demographic variables.

The results from the regression analysis of the three case study area data and the student data are given in Tables 6.34 and 6.35. B is the variable coefficient, Beta is the standard partial regression coefficient and t is the student's t value.

The three case study area regression model for ($L_{A10} - L_{A90}$) has only one variable that makes a significant contribution to explaining the variance in $L_{A10} - L_{A90}$ at the 5% confidence level: traffic-road density. Whilst the student regression equation for $L_{A10} - L_{A90}$ has no variables which make a significant contribution at the 5% confidence level.

The regression analysis for the three case study areas was re-run including only the traffic density variable. The resultant model is given in equation form below. The letter 'D' stands for traffic density (veh.km/hr/km²) and the figures in brackets are the student's t values.

$$\begin{aligned}
 (L_{A10} - L_{A90}) &= 13.312249 - 8.906884 \times 10^{-4} D \\
 &\quad (22.896) \quad (4.646)
 \end{aligned}$$

Table 6.34 Results the regression analysis of ($L_{A10} - L_{A90}$) against the demographic variables - three case study area data

Multiple R	0.64400
R Square	0.41473
Adjusted R Square	0.35313
Standard Error	1.76429

Variable	B	Standard Error of B	Beta	t	Significance of t
Traffic-road density	-8.75165×10^{-4}	1.9575×10^{-4}	-0.577082	-4.471	0.0001
% Residential land	0.019906	0.010682	0.252231	1.864	0.0701
% Commercial land	-0.016768	0.048748	-0.044365	-0.344	0.7328
% Industrial land	-0.002142	0.015357	-0.018885	-0.139	0.8898
(Constant)	12.468857	0.822660		15.157	0.0000

Table 6.35 Results of the regression analysis of ($L_{A10} - L_{A90}$) against the demographic variables - student data

Multiple R	0.12122
R Square	0.01469
Adjusted R Square	-0.00215
Standard Error	6.32703

Variable	B	Standard Error of B	Beta	t	Significance of t
Traffic-road density	-4.47766×10^{-4}	3.5727×10^{-4}	-0.082137	-1.253	0.2114
% Residential land	0.020371	0.015272	0.087174	1.334	0.1835
% Industrial land	0.002711	0.065137	0.002728	0.042	0.9668
% Commercial land	0.031351	0.074210	0.027987	0.422	0.6731
(Constant)	12.781781	1.254658		10.187	0.0000

Table 6.36 Results from F-tests for 'parallel' regional models and for significantly different constants for the $L_{A10} - L_{A90}$ variable - Three case study area data

Test	F ratio	Degrees of freedom 1	Degrees of freedom 2
Parallel models	0.9070	8	28
Different constants	0.3674	2	36

Multiple R	= 0.58732
R square	= 0.34494
Adjusted R square	= 0.32897
Standard error	= 1.79694

The model describes 34.5% of the variability of noise levels and has a standard error of estimate of 1.8 dB(A). The results suggest that the variability in noise levels is inversely related to traffic density i.e. where roads have intermittent traffic the variability in noise levels will be higher.

The variability of noise levels has been linked with public annoyance (GRI 68) this indicates that noise nuisance due to traffic is more likely in areas where there is low traffic density. High traffic density areas will have steadier noise levels and may cause less annoyance despite the increased noise level overall.

The three case study area and student data were further tested to establish whether there is any significant difference in the variability of noise in the regions of the United Kingdom.

Multivariate regression analysis was used to test, firstly whether the data sets are comprised of 'parallel' regional models and secondly, if parallel, whether they have significantly different constants.

The method used to test the $(L_{A10} - L_{A90})$ values is described previously in Sections 6.3.1 and 6.3.2. The results for the F-tests for 'parallel' regional models and 'significantly different constants' for the three case study area data and the student data are given in Tables 6.36 and 6.37 respectively.

Table 6.37 Results from F-tests for 'parallel' regional models and for significantly different constants for the $L_{A10} - L_{A90}$ variable - Student data

Test	F ratio	Degrees of freedom 1	Degrees of freedom 2
Parallel models	0.9923	36	189
Different constants	0.6260	9	225

The 5% confidence level for 8/28, 2/36, 36/189 and 9/225 degrees of freedom are 2.29, 3.26, 1.45 and 1.92 respectively. It can be seen that, for both the three case study area data and the student data, the regional models are parallel and do not have significantly different regional constants at the 5% confidence level. Thus, there is no regional difference between the relationship ($L_{A10} - L_{A90}$) for the regions, land use categories and time periods tested using the three case study area data and the student data. Therefore the variability in noise between 10am. and 4pm., and between 6pm. and 10pm. is not significantly different for the regional groups used.

Table 6.38 Effect of external noise source on internal noise levels

Noise source	Distance (m.)	Number of measurements effected	Studentised residuals		
			L_{Aeq}	L_{A10}	L_{A90}
Trains	1000	1	0.001	0.00	-0.79
Motorway	750	19	-0.47	-0.32	1.26

6.5 Testing of Noise Hypothesis 1

The hypothesis that:

‘average noise levels within a 1 km² square are not significantly affected by noise produced by sources outside the 1 km² square’

is tested by:

- examining those 1 km² squares where noise from ‘external’ sources could be distinguished above the ambient environmental noise levels.
- examining those 1 km² where the studentised residuals⁶ from the regression model with regional constants exceed the ± 1.7 dB(A) theoretical standard error.

Thus, the effect of both the presence and lack of ‘external’ noise sources can be assessed.

Noise from sources external to the 1 km² squares surveyed were noted at a number of measurement locations within two of the 1 km² squares in Milton Keynes. The type of noise source, the number of measurement locations affected and the corresponding studentised residuals for each of the noise index regression models are given in Table 6.38.

It can be seen that the 1 km² square close to the M1 motorway does have quite a high studentised residual for the L_{A90} regression model but this error is still within the tolerable error of the model of 1.7 dB(A).

⁶The studentised residual is the residual divided by the estimate of its standard deviation that varies from point to point depending on the distance X_i from the mean X . It reflects the difference in the true error variances from point to point.

The assessment using the studentised residual is aided by the use of maps showing the three case study areas with the studentised residuals and predominant wind direction for each of the 1 km² squares surveyed. These maps are shown in Figures 6.7 to 6.15.

The studentised residuals are for $e \frac{L_{Aeq}}{10}$, $e \frac{L_{A10}}{10}$ and $e \frac{L_{A90}}{10}$ values therefore a studentised residual of 1.2 is equivalent to the 1.7 dB(A) theoretical standard error.

Careful examination of:

- the studentised residuals,
- noise sources identified and written onto the noise survey report form,
- the internal demographic characteristics and
- the external demographic characteristics

show that for each of the noise indices there are no obvious external noise sources or lack of noise sources which are significantly effecting internal arithmetic averaged measurements of L_{Aeq} , L_{A10} and L_{A90} .

In many of the 1 km² squares where the studentised residuals exceed ± 1.2 dB(A) the internal demographic characteristics can be hypothesised to be the cause. An example is the Bexley 1 km² square which includes an approximately 500m. by 500m. area of a local park and has unusually low levels of L_{Aeq} , L_{A10} and L_{A90} . These low levels may be due to the lack of noise sources including traffic in this area.

The results from testing of Noise Hypothesis 1 suggest that the 1 km² square spatial scale is appropriate for predicting L_{Aeq} , L_{A10} and L_{A90} in the areas studied. However, there may be a need for larger spatial scale for prediction in more rural areas or near airports.

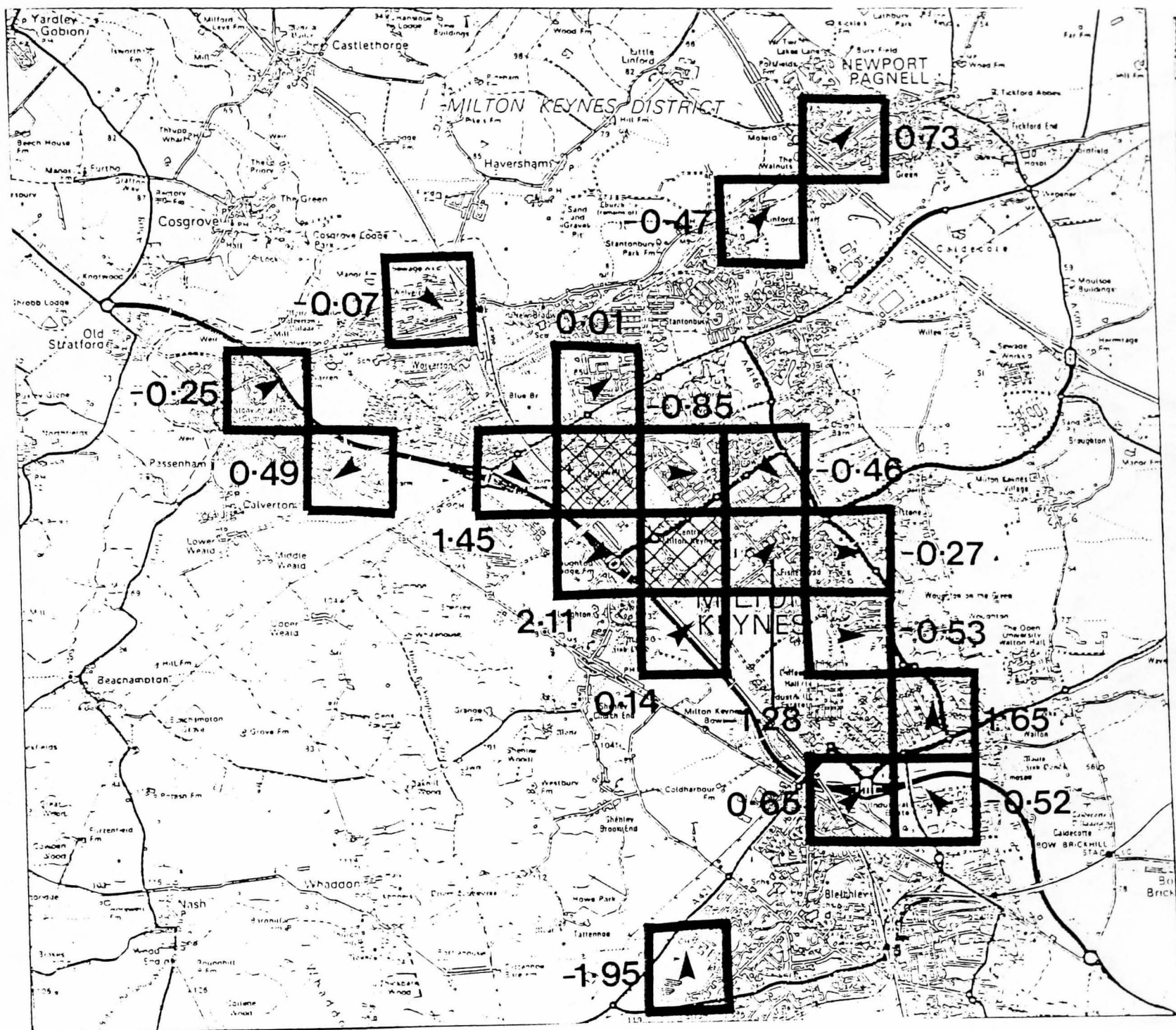


Figure 6.7 Wind direction and studentised residuals for the L_{Aeq} regression model - Milton Keynes

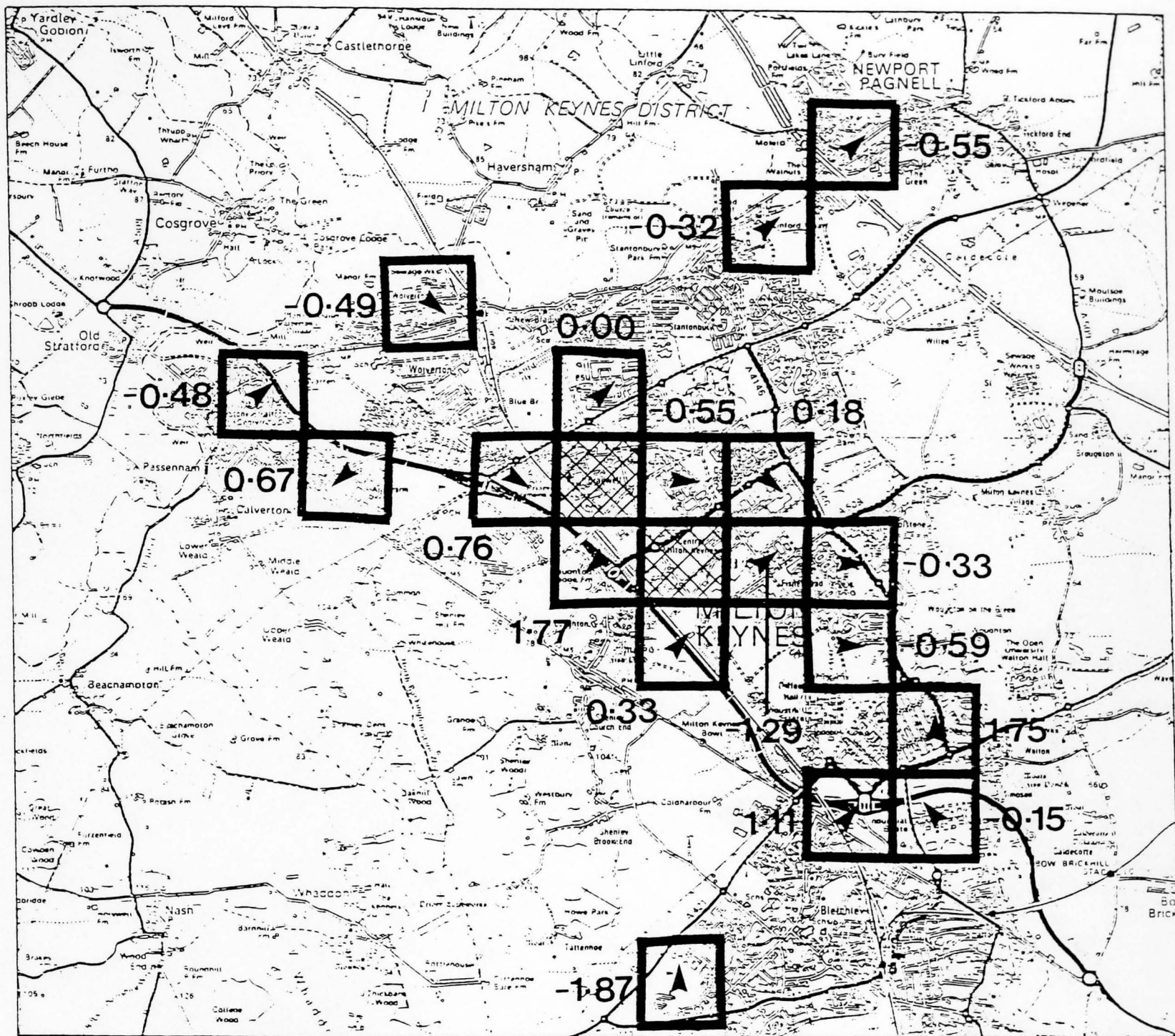


Figure 6.8 Wind direction and studentised residuals for the L_{410} regression model - Milton Keynes

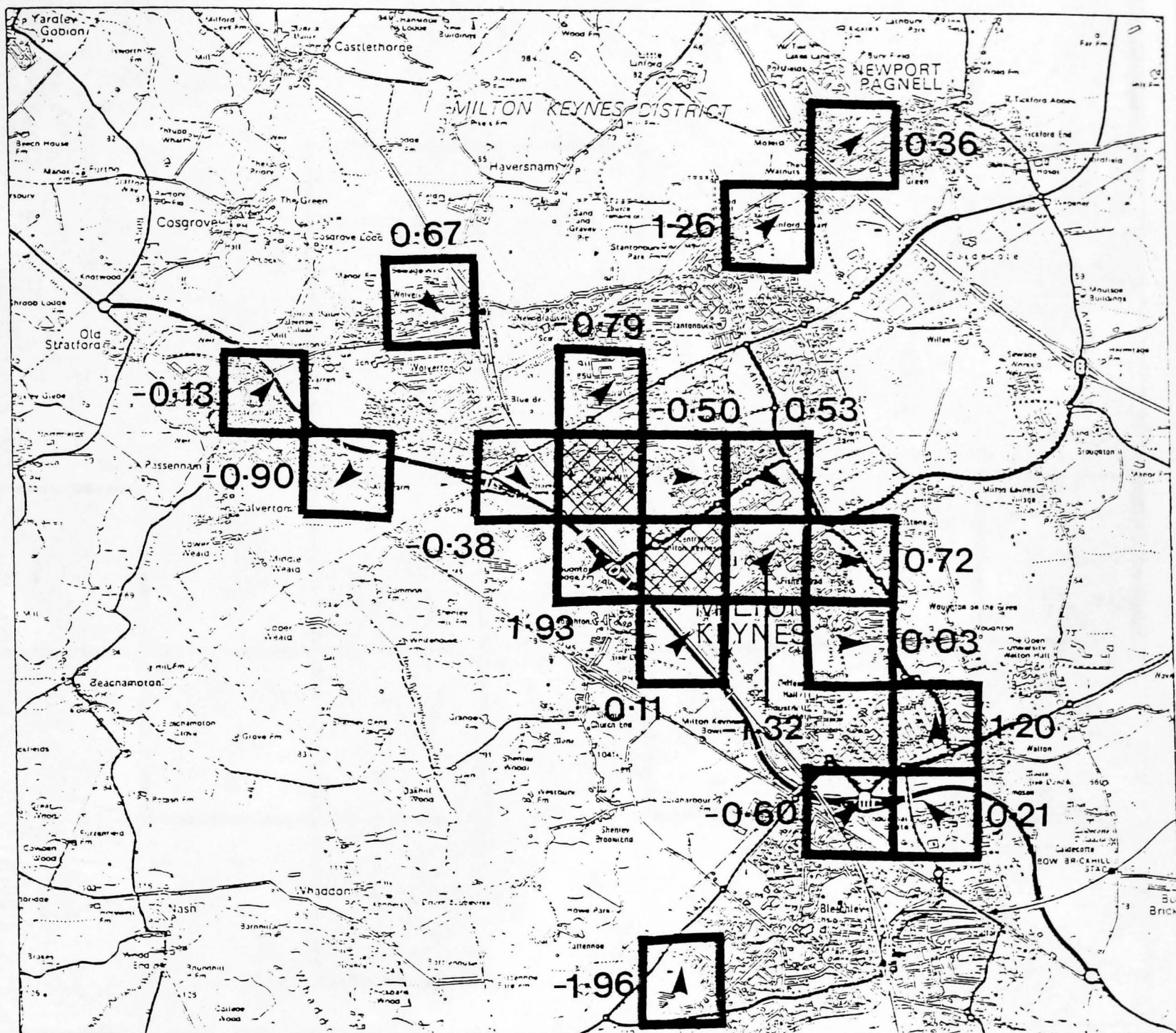


Figure 6.9 Wind direction and studentised residuals for the L_{490} regression model - Milton Keynes

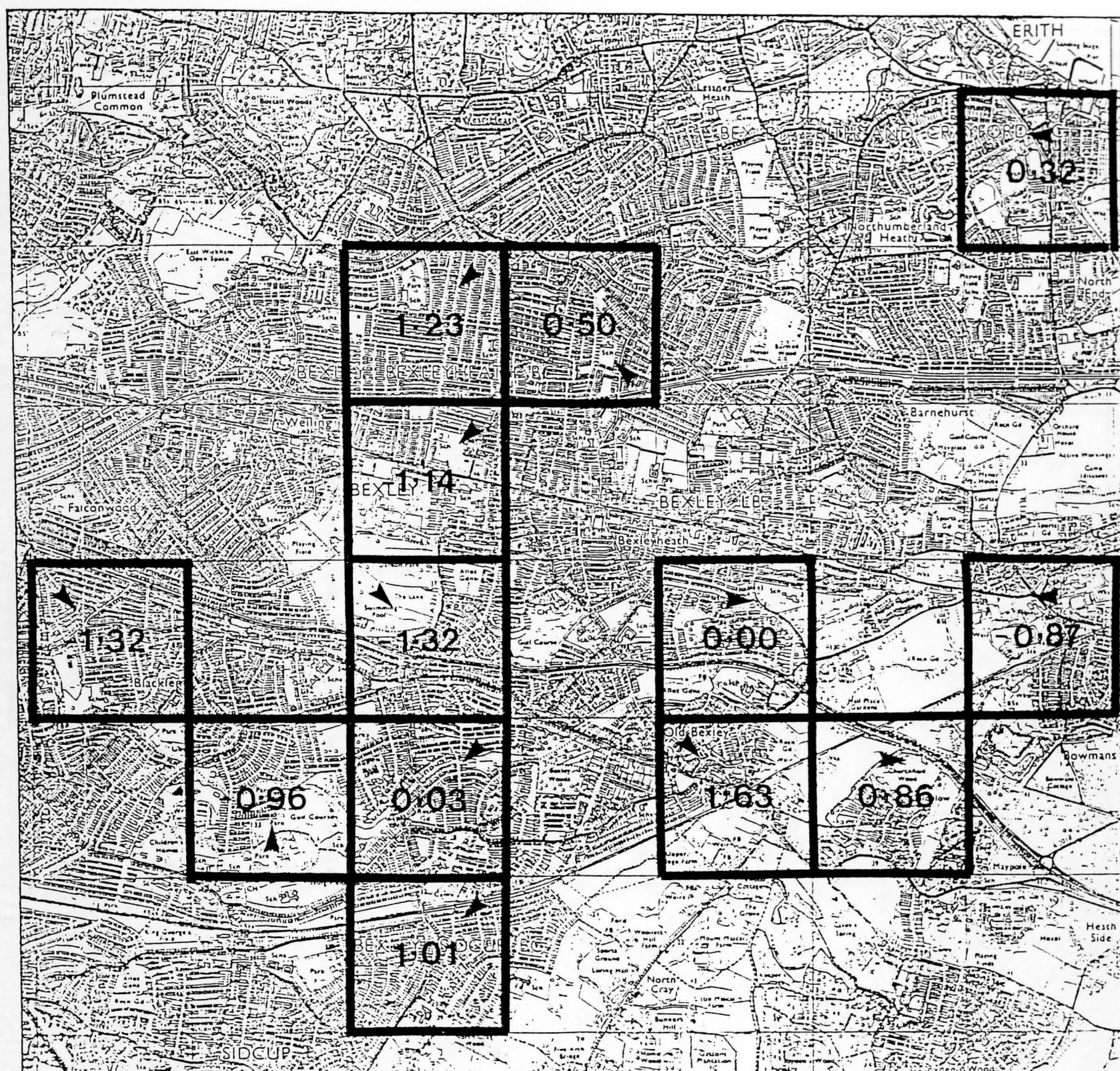


Figure 6.11 Wind direction and studentised residuals for the L_{A10} regression model - Bexley

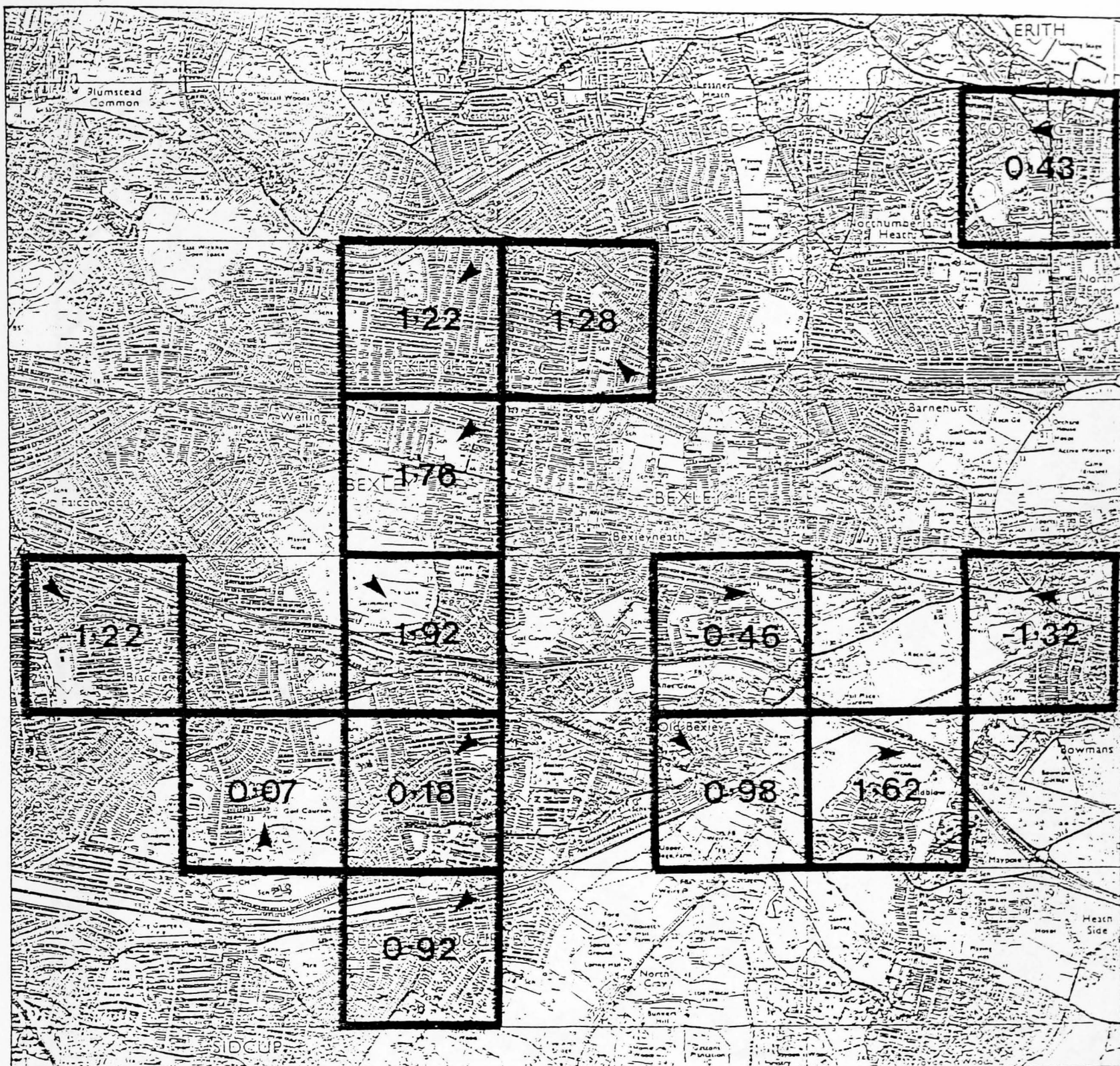


Figure 6.12 Wind direction and studentised residuals for the L_{A90} regression model - Bexley

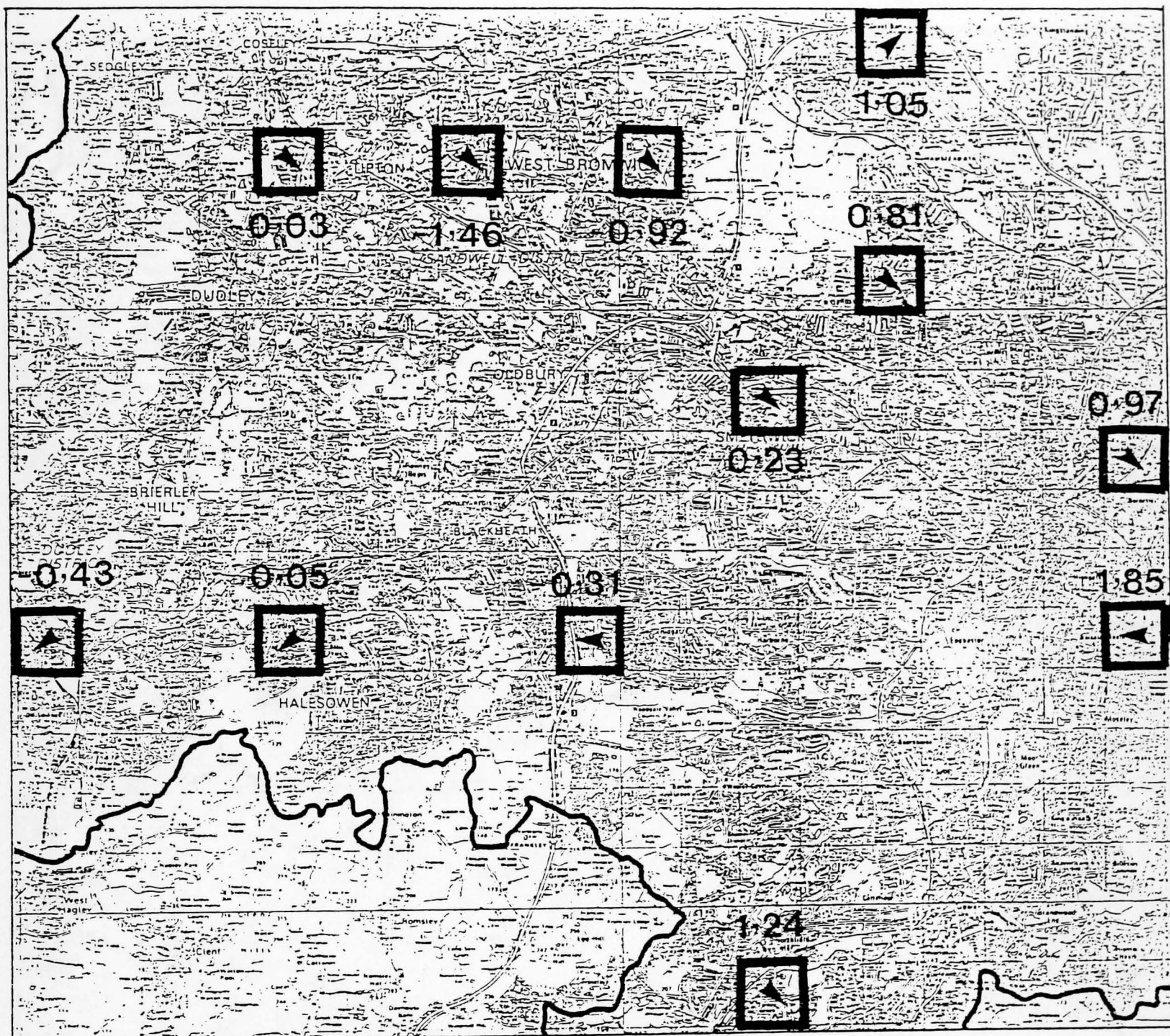


Figure 6.13 Wind direction and studentised residuals for the L_{Aeq} regression model - West Midlands

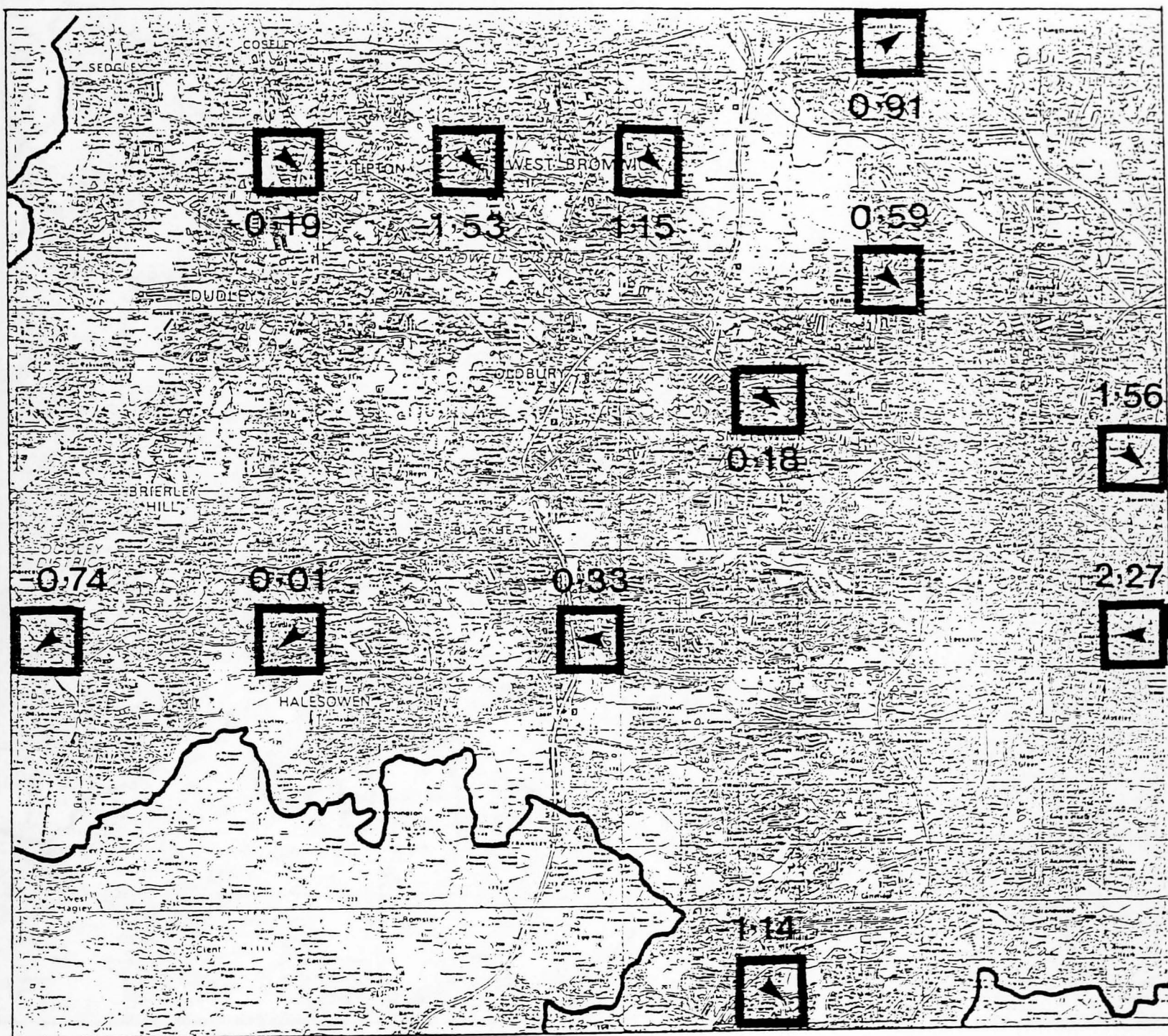


Figure 6.14 Wind direction and studentised residuals for the L_{A10} regression model - West Midlands

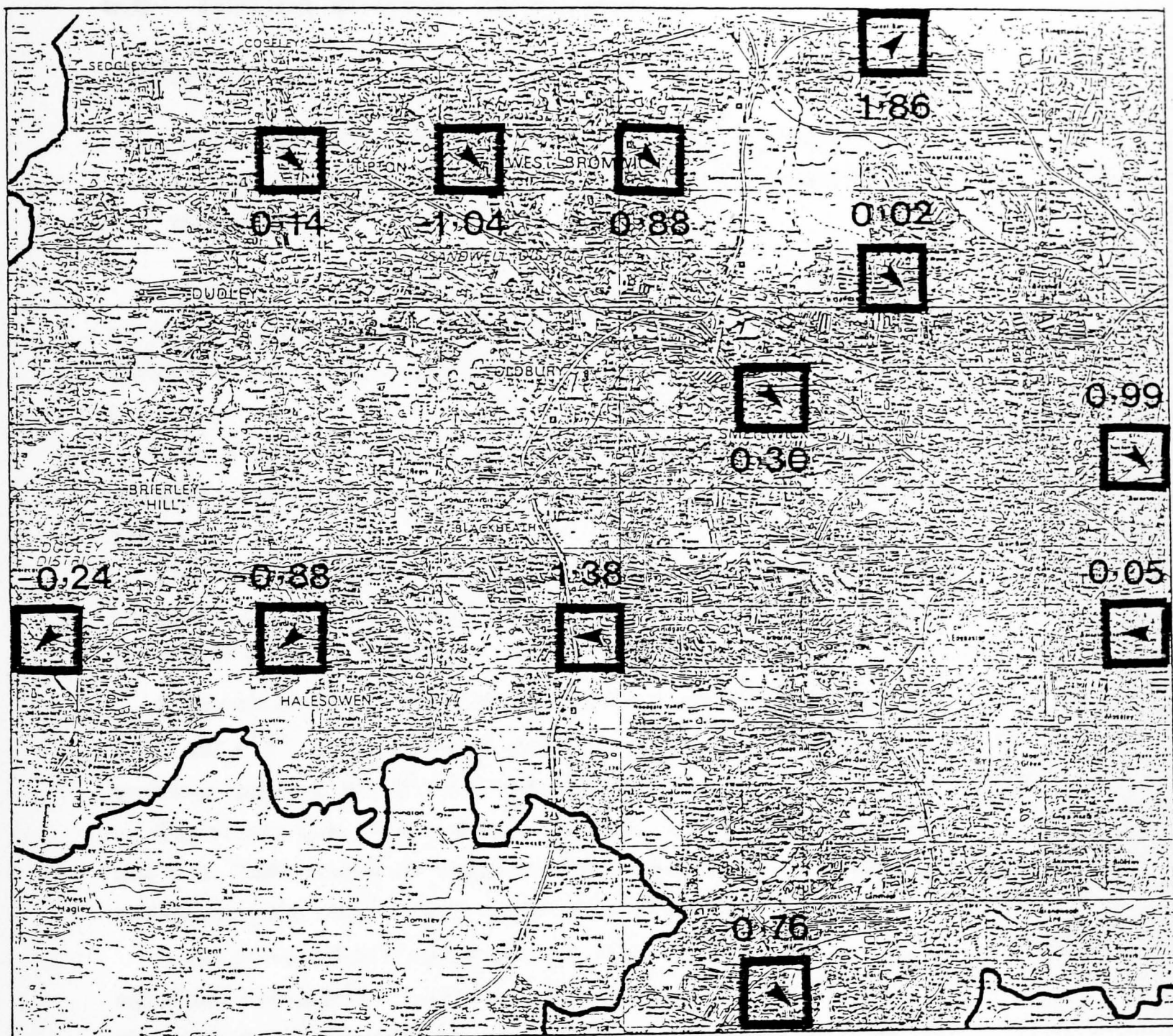


Figure 6.15 Wind direction and studentised residuals for the LA90 regression model - West Midlands

6.6 Testing of Noise Hypothesis 2

The hypothesis that:

'traffic density (veh.km/hr/km²) is a better predictor than network density when either is used in conjunction with land use classifications'

is tested by comparing the regression equations derived with the predictor variables land use and traffic-road density with those with the predictor variables land use and network density developed from the three case study area data.

Each of the 1 km² squares surveyed in the three case study areas is classified according to Pocock's road network density parameter, defined in Section 2.2.1.

The Pearson correlation coefficient and two-tailed significance for the correlation between traffic density and network density predictor variables are -0.1007 and 0.521 respectively (number of areas equals 43).

A regression analysis was performed on the dependent variables $e^{\frac{L_{Aeq}}{10}}$, $e^{\frac{L_{A10}}{10}}$ and $e^{\frac{L_{A90}}{10}}$ using the land use categories, and Pocock's network density predictor variables instead of the traffic density variable.

The results from these regression analyses are shown in Tables 6.39 and 6.41. These results are compared with the results from the regression models using the traffic density variable shown in Tables 6.8 to 6.10.

It can be seen that Pocock's network density variable does not make a significant contribution to explaining the variations in the dependent variable even at the 69% confidence level. However, the traffic density variable proposed in this research contributes to the explanation of the dependant variable at the 2% confidence level for the three case study area data. The results indicate that, for the area-types sampled, the traffic density variable proposed in this research is a better predictor of L_{Aeq} , L_{A10} and L_{A90} when either is used in conjunction with land use category predictor variables. However, the majority of the 1 km² squares surveyed in the case

Table 6.39 Results of full regression analysis using Pocock's network density variable - $e^{\frac{L_{Aeq}}{10}}$

Multiple R 0.45940
R Square 0.21105
Adjusted R Square 0.12800
Standard Error Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
Network density	0.145584	1.909334	0.017513	0.076	0.9396
% Industrial land use	2.343916	1.063823	0.382342	2.203	0.0337
% Commercial land use	-0.864810	2.995434	-0.042325	-0.289	0.7744
% Residential land use	-0.634761	1.060737	-0.148779	-0.598	0.5531
Constant	353.155132	46.821790		7.543	0.0000

Table 6.40 Results of full regression analysis using Pocock's network density variable - $e^{\frac{L_{A10}}{10}}$

Multiple R 0.44925
R Square 0.20182
Adjusted R Square 0.11781
Standard Error Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
Network density	0.203041	2.256672	0.020785	0.090	0.9288
% Industrial land use	2.734248	1.257349	0.379564	2.175	0.0360
% Commercial land use	-0.348620	3.540351	-0.014520	-0.98	0.9221
% Residential land use	-0.699947	1.253702	-0.139615	-0.558	0.5799
Constant	419.151558	55.339417		7.574	0.0000

Table 6.41 Results of full regression analysis using Pocock's network density variable - $e^{\frac{L_{A90}}{10}}$

Multiple R	0.45571
R Square	0.20767
Adjusted R Square	0.12426
Standard Error	Unknown

Variable	B	Standard Error of B	Beta	t	Significance of t
Network density	-0.376363	0.939014	-0.092253	-0.401	0.6908
% Industrial land use	1.115089	0.523190	0.370645	2.131	0.0396
% Commercial land use	1.056748	1.473160	0.105388	0.717	0.4776
% Residential land use	-0.202749	0.521672	-0.096834	-0.389	0.6997
Constant	147.216753	23.027035		6.393	0.0000

study areas have vehicle densities between 2001 and 4000 veh.km/hr/km². Pocock's intensity of land use variable may make a more significant contribution to explaining variations in these noise indices in areas where land use activities are more important sources of noise i.e. in 1 km² squares with low vehicle densities or in areas with high industrial land use and varying traffic densities.

Chapter 7

The Statistical Testing of the Research Hypotheses Relating to Air Pollution

7.1 Introduction

The National Survey of air pollution data supplied by Warren Spring Laboratory are used to test the general hypotheses outlined in Section 3.5.1. The hypotheses are tested for each of the selected measures of smoke and sulphur dioxide listed in Section 3.1.2

A statistical breakdown of each of the variables according to area-type, extent of smoke control and region is given at the end of Appendix 3.

As expected there are no measurements made in open space areas which are subject to smoke control, and few industrial areas which are subject to smoke control have been surveyed. The vast majority of monitoring has been done in residential and mixed residential areas.

Average concentrations of smoke in areas subject to smoke control are lower than in areas not subject to smoke control. However, the inverse is true for sulphur dioxide, where areas subject to smoke control have higher average sulphur dioxide concentrations .

Highest average levels of smoke are found in the residential/industrial land use categories which are not subject to smoke control. However the highest average concentrations of sulphur dioxide are found in industrial areas subject to smoke control.

7.2 Testing of General Hypothesis 1 - Air.

'That variations in the measures of smoke and sulphur dioxide are significantly associated with variations in demographic area-type classification.'

General Hypothesis 1 is tested using two-way analysis of variance techniques and multivariate regression analysis of the prediction matrix.

The prediction matrix is tested in two dimensions using data in the land use categories: residential, commercial, residential/industrial and residential/commercial/industrial as sufficient data in these categories exist to satisfy the selection criterion outlined in Section 3.4.2.

7.2.1 Tests Using Two-way Analysis of Variance

As stated in Chapter 6 there are three assumptions that the data should meet when using the analysis of variance statistical technique:

1. The individual sample sites should be selected on the basis of random sampling from a normally distributed population.
2. The variance of the mean sample site air pollution measures within each of the area-type classifications should be homogeneous.
3. The air pollution measurements representing the sample sites should be independent so that they thereby yield independent variable estimates and the ratio of within-area-classification variance and between-area-classification variance in air pollutant levels will have an F distribution.

The analysis of variance technique is robust in respect of these assumptions.

Preliminary tests were performed on the data to determine whether these assumptions were satisfied. The tests performed are:

1. Cochran's C-test of homogeneity.

2. Bartlett - Box F-test of homogeneity.
3. Normal plot¹.
4. Detrended Normal plot².

These tests were carried out on each of the variables of smoke and sulphur dioxide. It was found that the un-transformed variables for smoke do not satisfy the homogeneity of variance assumptions and that the normal and detrended normal plots indicated that none of the variables of smoke or sulphur dioxide have a normal distribution.

Larsen (LAR 66) has shown that temporal variations in air pollution approximate to a log-normal distribution. However, this analysis is investigating the spatial variations in air pollution and therefore it is necessary to explore a number of data transformations, including the log-normal transformation, to determine which gives the best approximation to normality and homogeneity of variance.

Of the analysis of variance assumptions the homogeneity of variance assumption is the most important in terms of producing accurate results.

Four transformations were applied to the data in an attempt to adjust the data so that they satisfy all of the analysis of variance assumptions. The data transformations investigated are logarithm (base 10), square-root, cube-root, and inverse. The results from the Cochran's C-test and Bartlett - Box F-test of homogeneity are given in Tables 7.1 and 7.2.

The homogeneity of variance assumption is normally rejected when P is less than 0.01 (for a 99% confidence limit) or 0.05 (for a 95% confidence limit).

It can be seen that the variables for smoke do not satisfy the homogeneity of variance assumption for any of the data transformations at either the 99% or 95% confidence levels. However, the best of the transformations is the square-root transformation as it minimises the Bartlett - Box F and Cochran's C values.

¹The normal plot is a plot of the expected normal value against the observed

²The detrended normal plot is a plot of the deviation from normal against the observed value

Table 7.1 Results of the Cochran's C-test of homogeneity of variance

		Cochran's C-Test				
		Un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	Inverse variable
Smoke winter median	C =	0.2372	0.2925	0.2201	0.2358	0.6811
	P =	0.000	0.000	0.000	0.000	0.000
Smoke yearly arithmetic mean	C =	0.2309	0.2655	0.2159	0.2283	0.5415
	P =	0.000	0.000	0.000	0.000	0.000
Smoke yearly median	C =	0.2254	0.2742	0.2092	0.2250	0.6049
	P =	0.000	0.000	0.000	0.000	0.000
Smoke yearly 98th percentile	C =	0.2247	0.2409	0.2013	0.2115	0.4450
	P =	0.000	0.000	0.000	0.000	0.000
SO ₂ winter median	C =	0.1591	0.2570	0.1537	0.1769	0.8951
	P =	0.116	0.000	0.251	0.005	0.000
SO ₂ yearly arithmetic mean	C =	0.1516	0.1901	0.1467	0.1590	0.3371
	P =	0.340	0.000	0.619	0.123	0.000
SO ₂ median	C =	0.1438	0.2247	0.1505	0.1684	0.8160
	P =	0.850	0.000	0.390	0.028	0.000
SO ₂ 98th percentile	C =	0.1573	0.1704	0.1528	0.1530	0.2339
	P =	0.158	0.019	0.292	0.285	0.000

Table 7.2 Results of the Bartlett - Box F-tests for homogeneity of variance

		Bartlett - Box F-test				
		Un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	Inverse variable
Smoke winter median	F = P =	19.1246 0.000	21.6897 0.000	14.3362 0.000	14.8749 0.000	129.592 0.000
Smoke yearly arithmetic mean	F = P =	17.1302 0.000	18.3475 0.000	14.2057 0.000	14.5912 0.000	77.4901 0.000
Smoke yearly median	F = P =	14.9729 0.000	18.9079 0.000	12.4991 0.000	13.2896 0.000	100.1540 0.000
Smoke yearly 98th percentile	F = P =	12.5280 0.000	12.7308 0.000	10.2216 0.000	10.4076 0.000	48.0490 0.000
Sulphur dioxide winter median	F = P =	0.4232 0.888	12.4355 0.000	1.3103 0.240	3.0036 0.004	227.068 0.000
SO ₂ Yearly arithmetic mean	F = P =	0.4992 0.836	4.2970 0.000	1.1867 0.306	1.8736 0.069	27.7322 0.000
SO ₂ Yearly median	F = P =	0.5841 0.769	8.6119 0.000	1.5752 0.137	2.8049 0.006	164.238 0.000
SO ₂ Yearly 98th percentile	F = P =	1.1746 0.313	2.5664 0.012	1.2794 0.256	1.5645 0.141	9.8598 0.000

The homogeneity of variance assumption is satisfied for the measures of sulphur dioxide either un-transformed or when the square-root transformation is used. The square-root transformation also improves the normality of the sulphur dioxide data. The normal and detrended plots for the square-root sulphur dioxide variables are shown in Figures 7.1 and 7.2.

A two-way analysis of variance test was therefore performed on each of the square-root transformed variables for sulphur dioxide. Although the conditions for analysis of variance were not wholly satisfied, these transformations were chosen as the basis for analysis since they represented the best available match to the requirements.

The analysis of variance technique tests the null hypothesis that 'there is no significant relationship between the measurements and the predictor variables'. A significant relationship is defined as a relationship at which the null hypothesis can be rejected at or within the 5% confidence limit.

Results From the Two-way Analysis of Variance Tests

Tables 7.3 to 7.6 show the results of each of the two-way analysis of variance tests and their associated F-tests performed on each of the measures of sulphur dioxide (square-root values).

The results show, firstly, that the null hypothesis: 'there is no relationship between the land use classification and the measures sulphur dioxide', can be rejected at the 0.1% limit for all the measures of sulphur dioxide. i.e. it is 99.9% certain that a statistically significant proportion of the observed variance in sulphur dioxide concentrations can be explained by variations in the land use category of the area where the observations were made.

Secondly, the null hypothesis: 'there is no relationship between the smoke control classification and measures of sulphur dioxide', can also be rejected at the 0.1% confidence limit i.e. the prediction matrix smoke control classifications are 99.9% certain to group the measures of sulphur dioxide studied into significantly different groups.

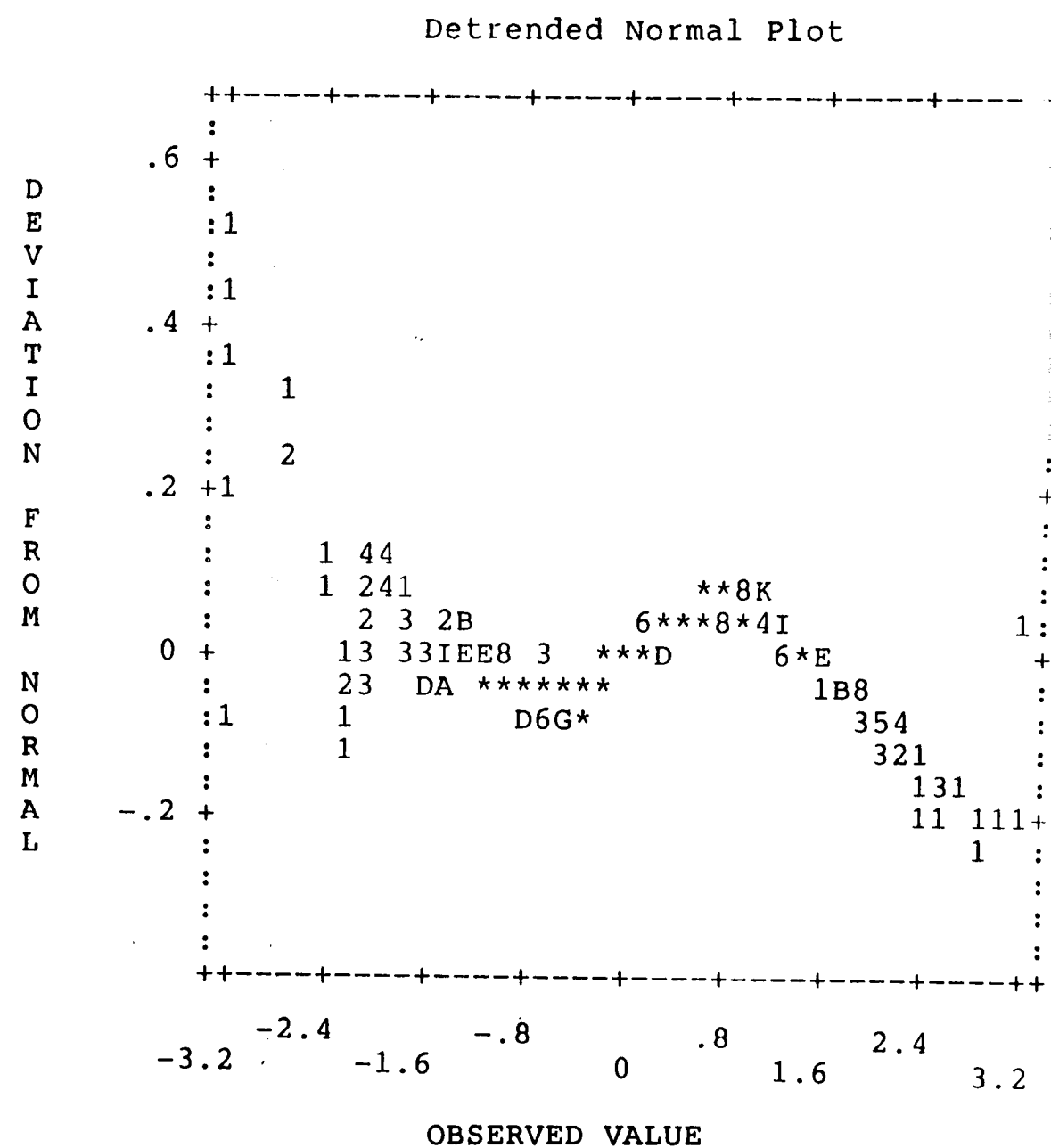
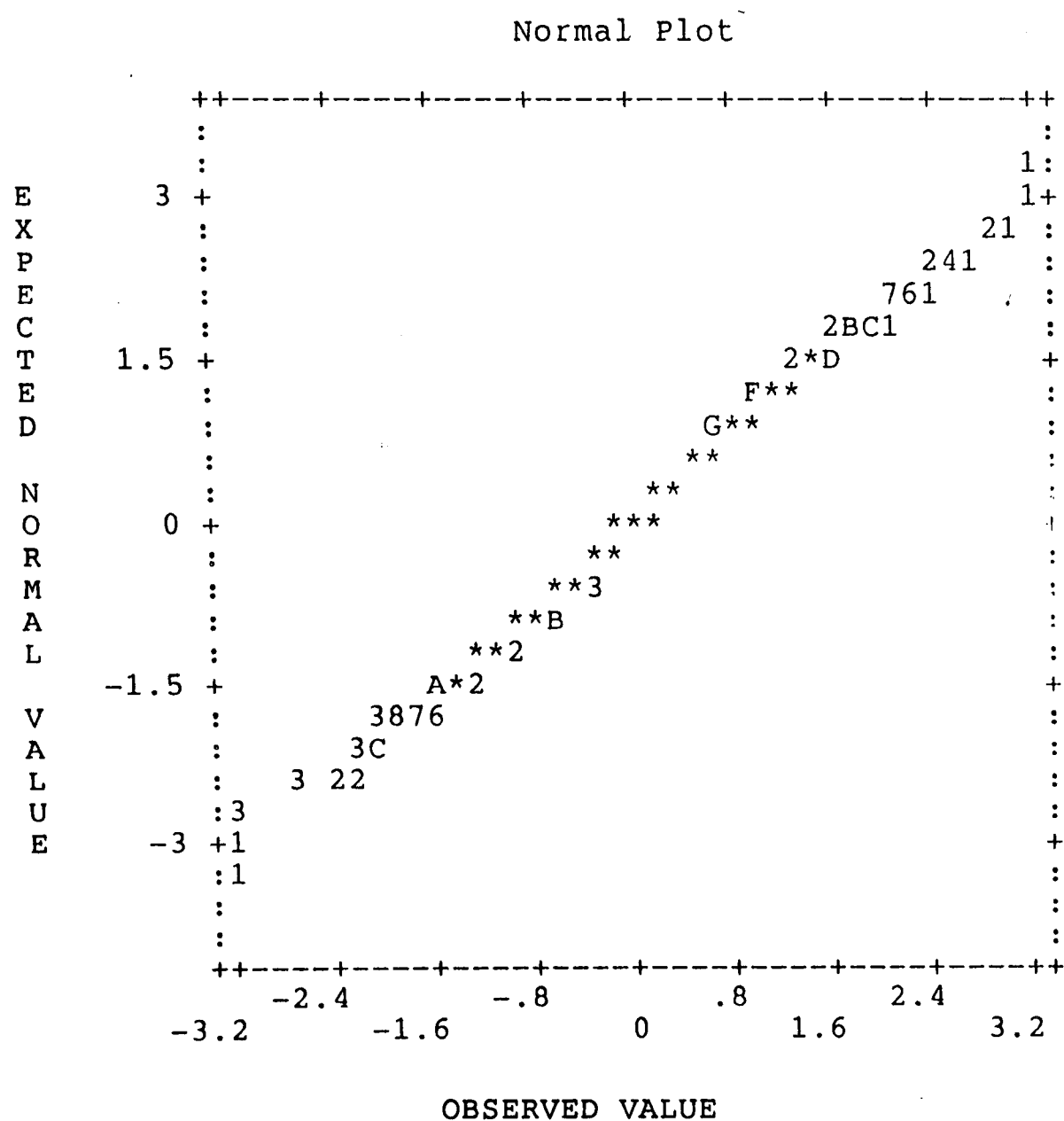


Figure 7.1 Normal and detrended normal plots for winter median of the daily values of sulphur dioxide - square root values

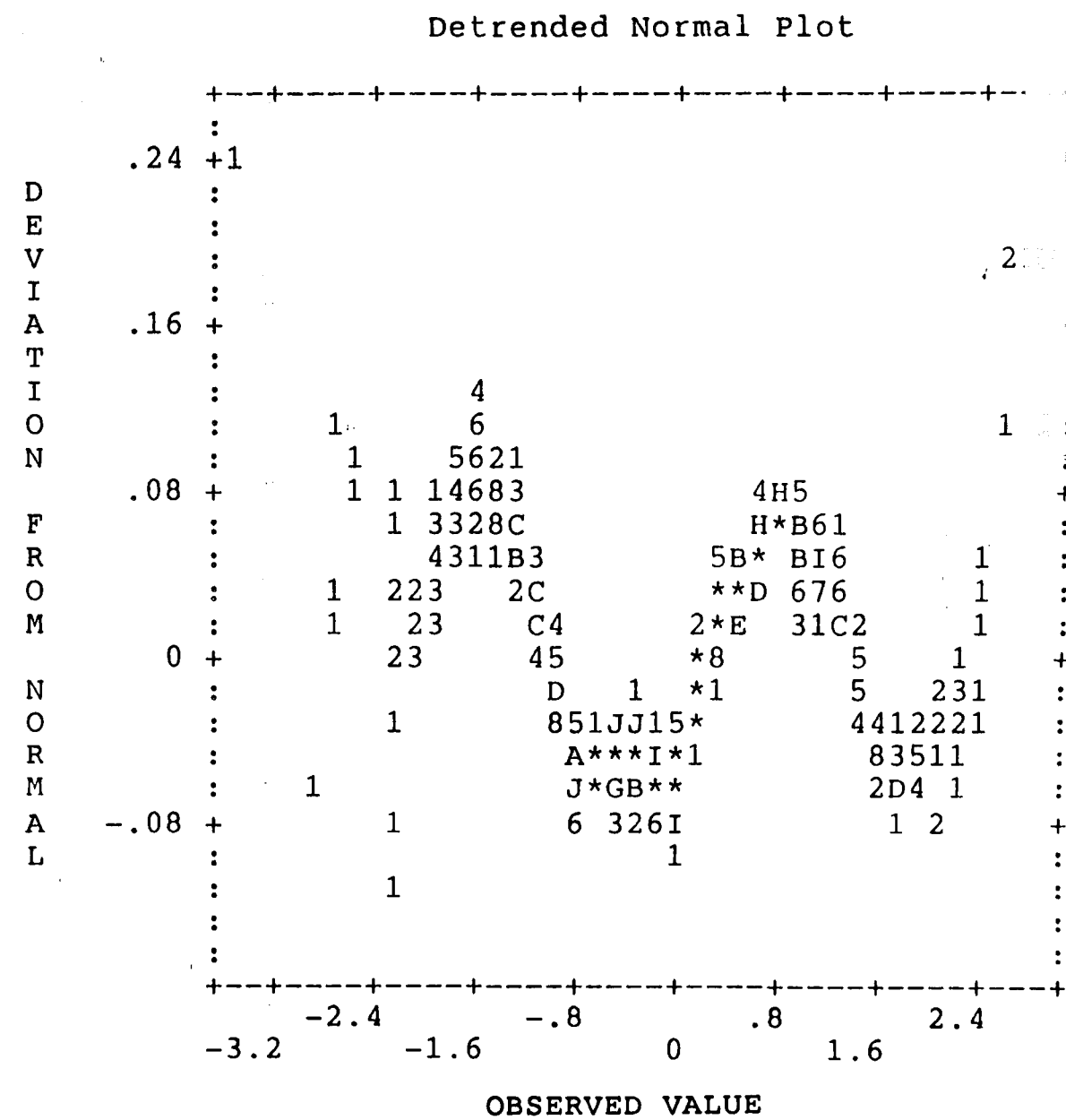
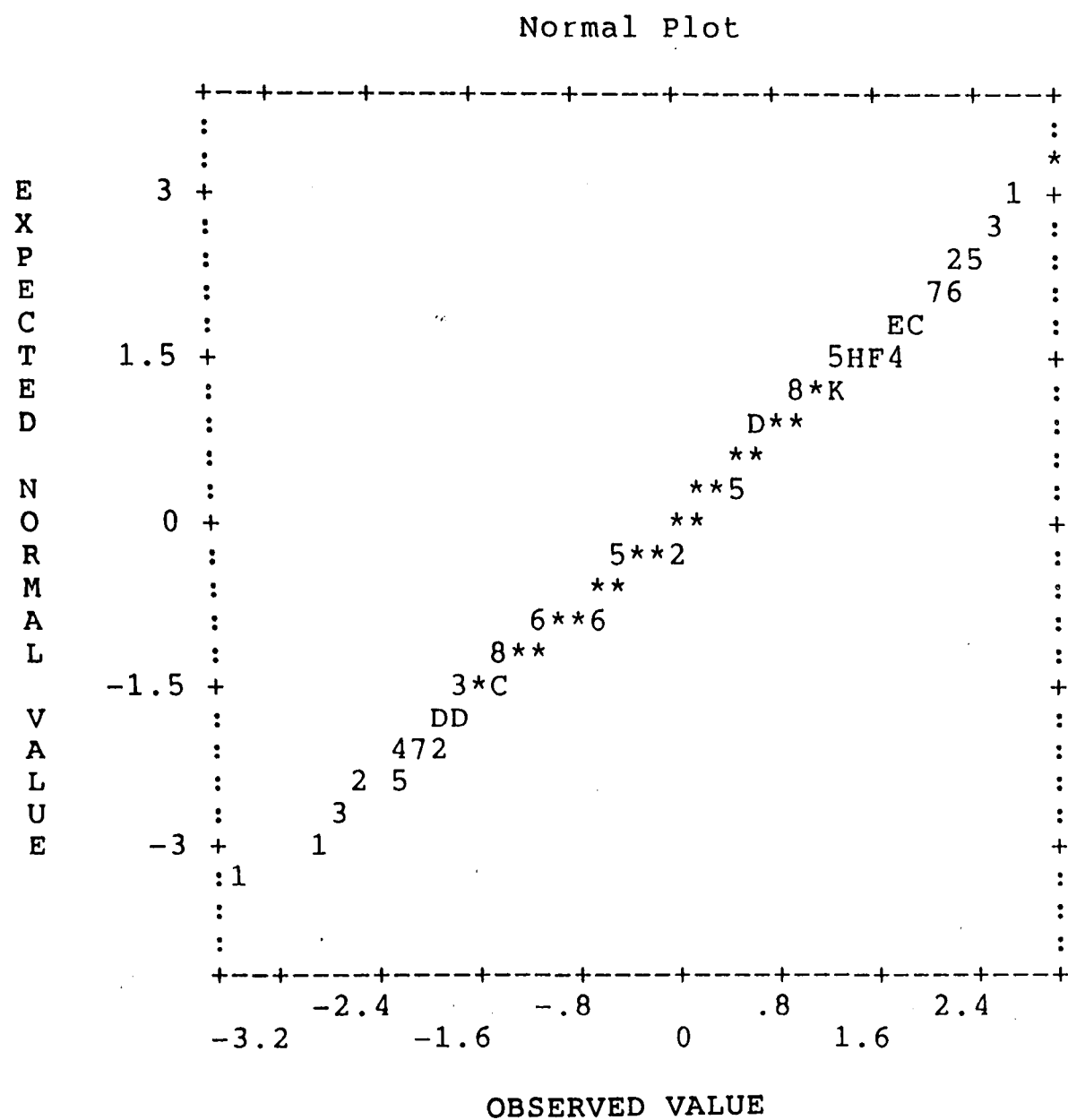
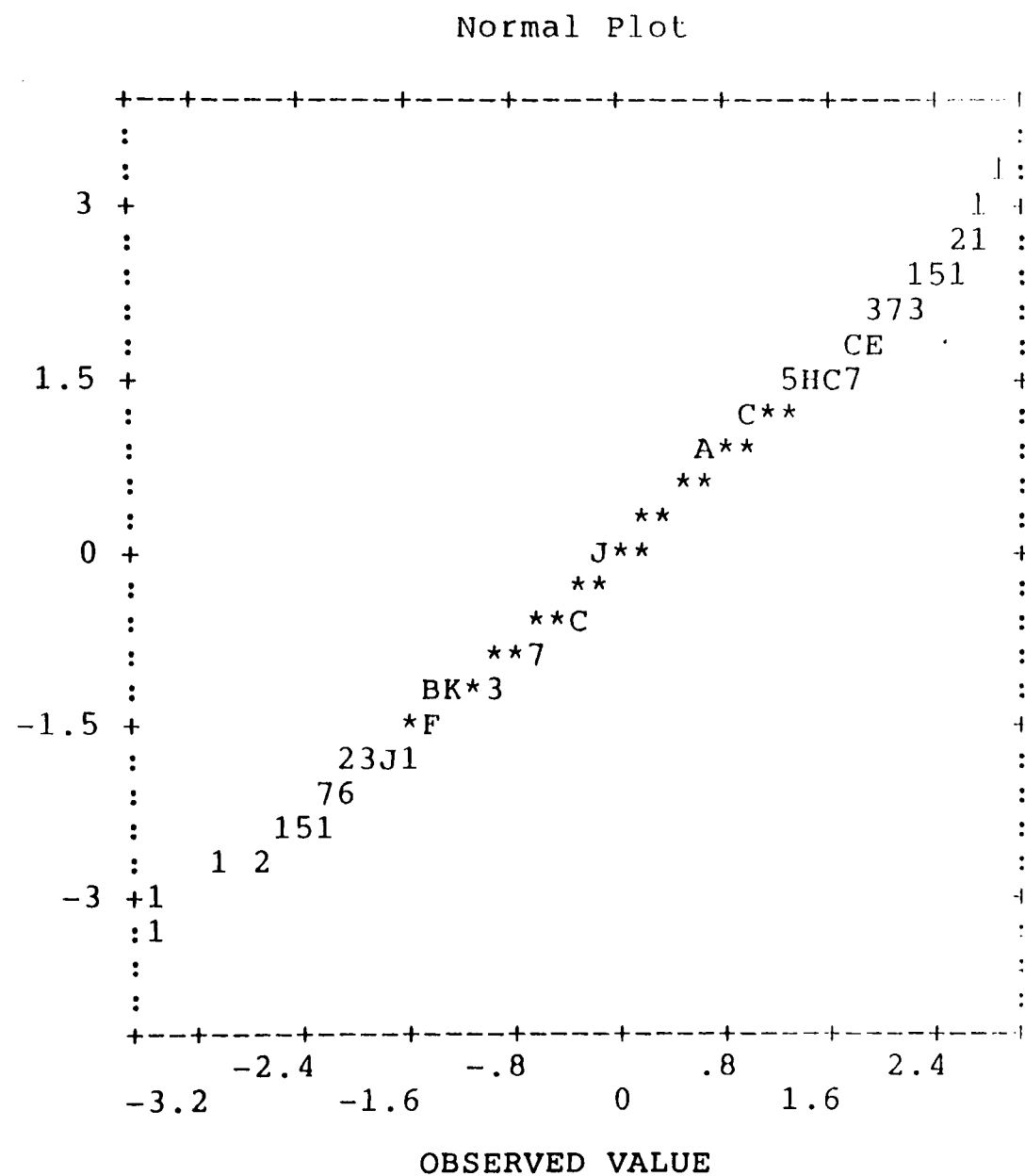


Figure 7.2 Normal and detrended normal plots for yearly mean of the daily values of sulphur dioxide - square root values

N
O
R
M
A
L

V
A
L
U
E



D
E
V
I
A
T
I
O
N

F
R
O
M

N
O
R
M
A
L

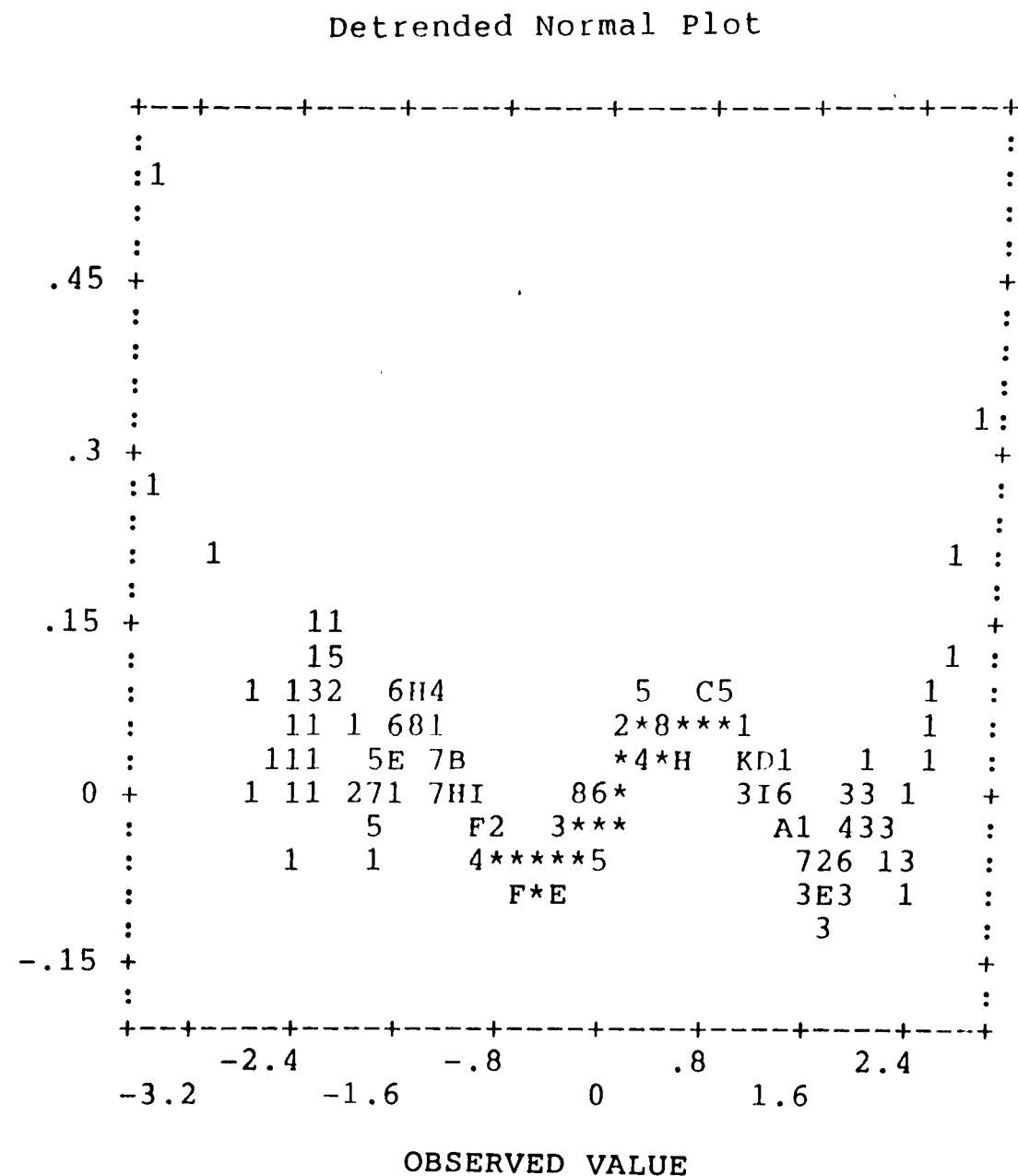


Figure 7.3 Normal and detrended normal plots for yearly median of the daily values of sulphur dioxide - square root values

11
 12
 13
 14
 15
 16
 17
 18
 19
 20
 21
 22
 23
 24
 25
 26
 27
 28
 29
 30
 31
 32
 33
 34
 35
 36
 37
 38
 39
 40
 41
 42
 43
 44
 45
 46
 47
 48
 49
 50
 51
 52
 53
 54
 55
 56
 57
 58
 59
 60
 61
 62
 63
 64
 65
 66
 67
 68
 69
 70
 71
 72
 73
 74
 75
 76
 77
 78
 79
 80
 81
 82
 83
 84
 85
 86
 87
 88
 89
 90
 91
 92
 93
 94
 95
 96
 97
 98
 99
 100

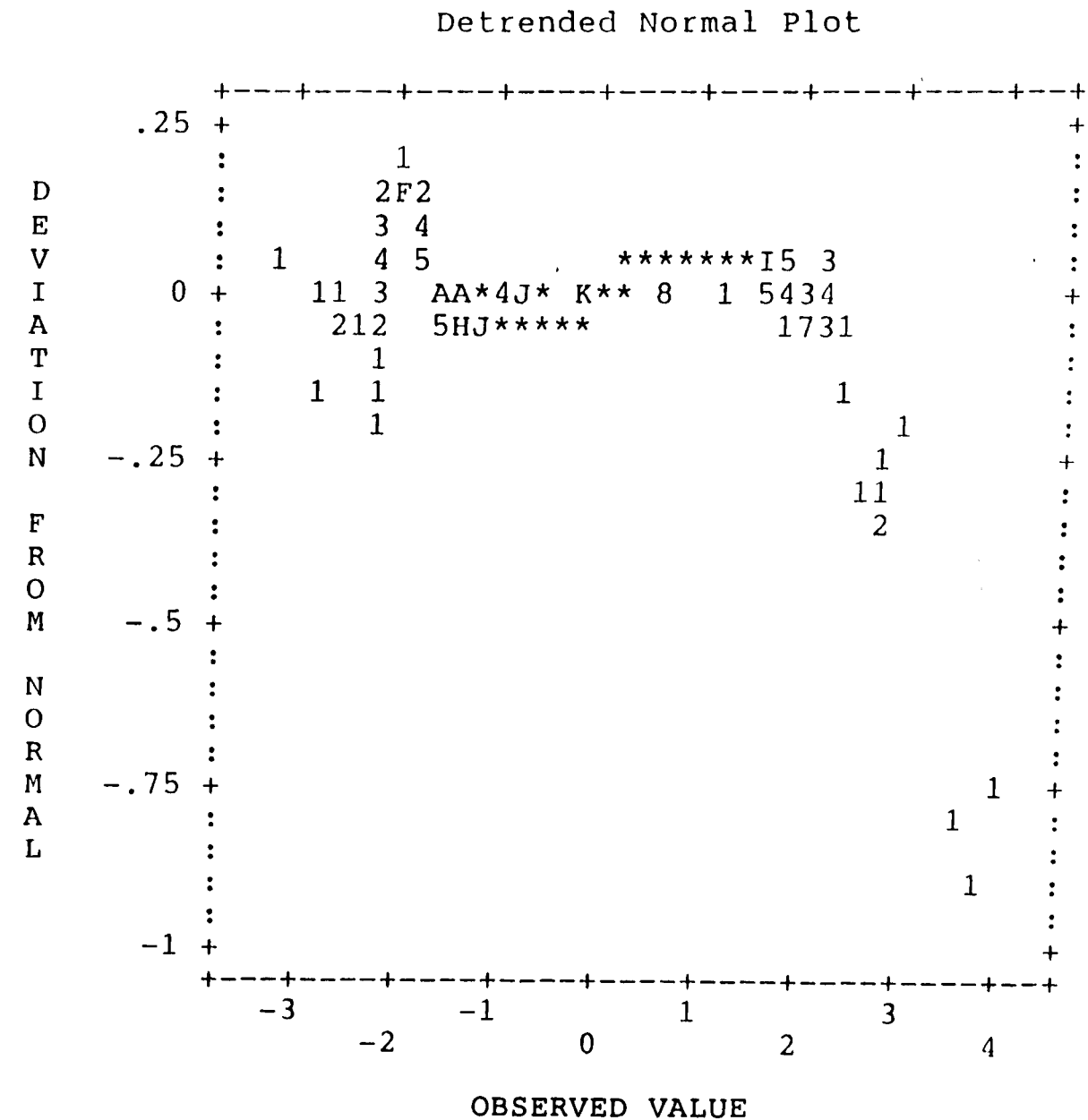
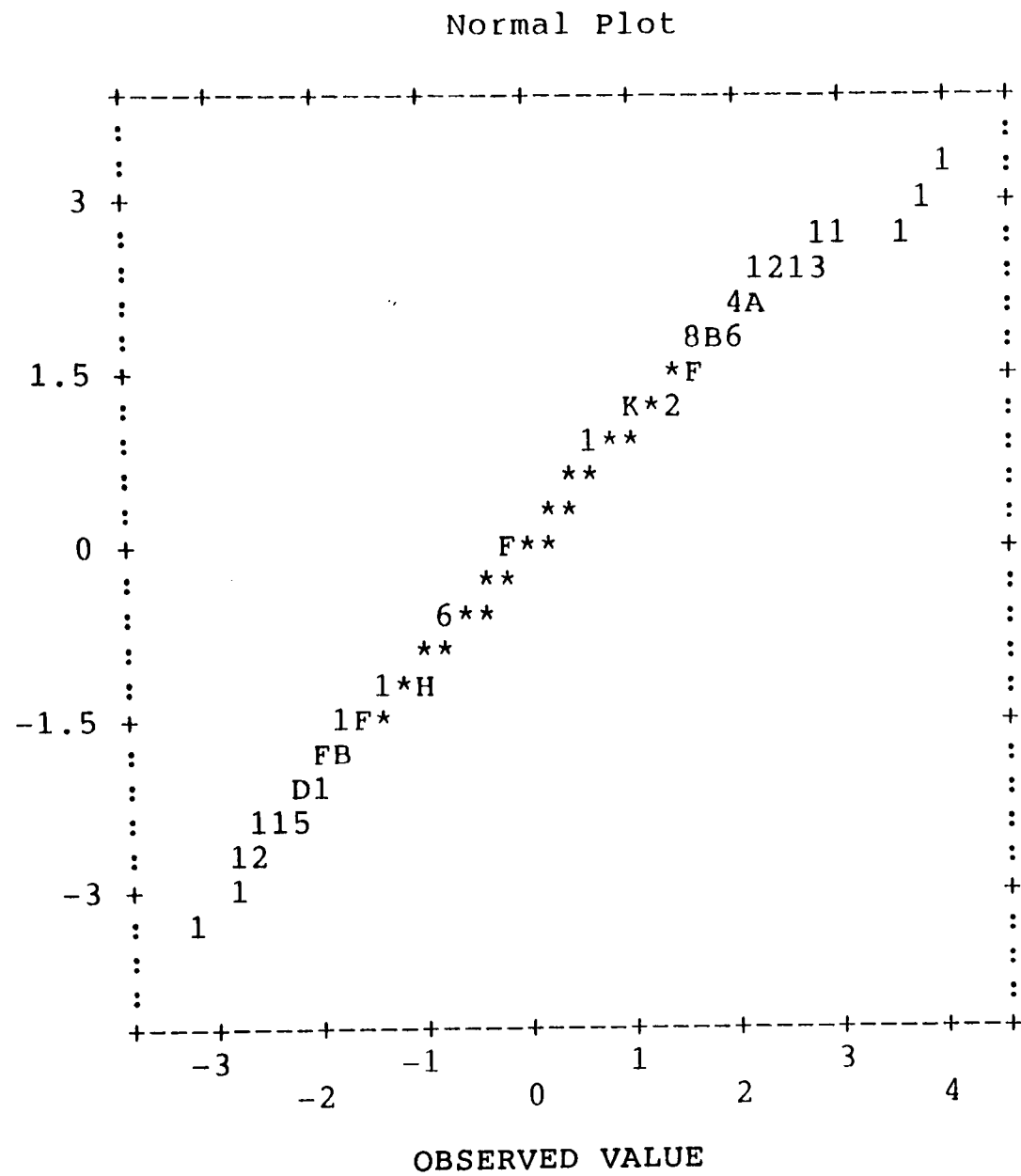


Figure 7.4 Normal and detrended normal plots for yearly 98th percentile of the daily values of sulphur dioxide - square root values

Table 7.3 Results from the two-way analysis of variance - square-root of Sulphur-dioxide-winter-median

Source of variation	Sums of squares	Degrees of freedom	Mean squares	F ratio	Significance of F
Within cells	2310.24	996	2.32		
Land use	105.19	3	35.06	15.12	0.000
Smoke control	46.06	1	46.06	19.86	0.000
Land use by smoke control	3.34	3	1.11	0.48	0.697

Table 7.4 Results from the two-way analysis of variance - square-root of Sulphur-dioxide-yearly-arithmetic-mean

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F ratio	Significance of F
Within cells	1839.26	986	1.87		
Land use	70.31	3	23.44	12.56	0.000
Smoke control	38.68	1	38.68	20.74	0.000
Land use by smoke control	3.87	3	1.29	0.69	0.557

The null hypothesis for interaction effects between land use and smoke control is not rejected for any of the sulphur dioxide variables. This indicates that the influence of smoke control acts independently of land use, despite the potential association between these two variables.

Conclusions

The conclusions drawn from the two-way analysis of variance tests on the prediction model matrix is that the land use categories: residential, commercial, residential/industrial and residential/commercial/industrial and the smoke control prediction variables are all determinants of sulphur dioxide concentrations.

Table 7.5 Results from the two-way analysis of variance - square-root of Sulphur-dioxide-yearly-median

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F ratio	Significance of F
Within cells	1834.08	986	1.86		
Land use	72.52	3	24.17	13.00	0.000
Smoke control	34.45	1	34.45	18.52	0.000
Land use by smoke control	3.68	3	1.23	0.66	0.578

Table 7.6 Results from the two-way analysis of variance - square-root of Sulphur-dioxide-yearly-98th-percentile

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F ratio	Significance of F
Within cells	4326.08	986	4.39		
Land use	97.89	3	32.63	7.44	0.000
Smoke control	101.47	1	101.47	23.13	0.000
Land use by smoke control	14.70	3	4.90	1.12	0.341

7.2.2 Identification of Pairs of Significantly Different Area-types

A one-way analysis of variance test is performed on the area-types defined in the previous analysis. The analysis is followed by a Scheffé test (SCH 53), described in Section 6.2.5, to determine which pairs of area-type classifications have significantly different air pollution levels.

The un-transformed data for smoke and sulphur dioxide do not satisfy the normality and homogeneity of variance assumptions as tested by the normal and detrended plots, and Bartlett - Box F-test and Cochran's C-test respectively.

A number of transformations were applied to the data with the intention of meeting the analysis of variance assumptions for the data.

The results of the Cochran's C-test and Bartlett - Box F-test of homogeneity of variance are given in Tables 7.7 and 7.8.

It can be seen that the variables for smoke do not satisfy the homogeneity of variance assumptions at either the 99% or 95% confidence levels. However, the best transformation is the square-root transformation as it minimises the Bartlett - Box F and Cochran's C values whilst improving the normality of the data.

The homogeneity of variance assumption is satisfied for the sulphur dioxide variables either un-transformed or with the square-root transformation. However the square-root transformation gives the data the best normal distribution.

Results from the Scheffé Test

The results from the Scheffé test of the two dimensional prediction matrix are shown in Table 7.9.

It can be seen that, for all of the sulphur dioxide measures except for the 98th percentile values, there are five pairs of area-types which have significantly different air pollution levels. However, there are only four significantly different pairs for the 98th percentile measures. The same pattern

Table 7.7 Results from the Cochran's C-test of homogeneity

		Cochran's C-test				
		Un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	Inverse variable
Smoke winter median	C = P =	0.2278 0.000	0.2079 0.000	0.2045 0.000	0.2013 0.000	0.4181 0.000
Smoke yearly arithmetic mean	C = P =	0.2237 0.000	0.2109 0.000	0.2105 0.000	0.2092 0.000	0.3127 0.000
Smoke yearly median	C = P =	0.2205 0.000	0.2050 0.000	0.2010 0.000	0.2000 0.000	0.3909 0.000
Smoke yearly 98th percentile	C = P =	0.2178 0.000	0.1956 0.000	0.1976 0.000	0.1959 0.000	0.2282 0.000
SO ₂ Winter median	C = P =	0.1620 0.108	0.1640 0.081	0.1464 0.730	0.1445 0.885	0.7221 0.000
SO ₂ Yearly arithmetic mean	C = P =	0.1540 0.324	0.1558 0.261	0.1448 0.885	0.1484 0.613	0.2302 0.000
SO ₂ Yearly median	C = P =	0.1463 0.759	0.1698 0.037	0.1434 1.000	0.1471 0.699	0.7634 0.000
SO ₂ 98th percentile	C = P =	0.1591 0.172	0.1565 0.238	0.1549 0.293	0.1549 0.290	0.1881 0.002
Smoke/SO ₂ winter median	C = P =	0.3712 0.000	0.1507 0.456	0.2092 0.000	0.1829 0.000	0.2075 0.000

Table 7.8 Results from the Bartlett - Box F-test of homogeneity

		Bartlett - Box F-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke winter median	F =	20.418	9.599	12.573	11.009	38.465
	P =	0.000	0.000	0.000	0.000	0.000
Smoke yearly arithmetic mean	F =	18.350	11.255	13.081	12.070	22.766
	P =	0.000	0.000	0.000	0.000	0.000
Smoke yearly median	F =	15.686	9.984	11.103	10.317	33.530
	P =	0.000	0.000	0.000	0.000	0.000
Smoke yearly 98th percentile	F =	13.504	7.812	9.433	8.620	12.066
	P =	0.000	0.000	0.000	0.000	0.000
SO ₂ winter median	F =	0.638	2.105	0.444	0.648	111.465
	P =	0.725	0.039	0.875	0.716	0.000
SO ₂ Yearly arithmetic mean	F =	0.710	1.445	0.708	0.851	11.612
	P =	0.663	0.182	0.665	0.544	0.000
SO ₂ Yearly median	F =	0.658	2.817	0.812	1.103	122.153
	P =	0.708	0.006	0.577	0.358	0.000
SO ₂ Yearly 98th percentile	F =	1.170	1.454	0.913	1.005	6.043
	P =	0.316	0.179	0.495	0.425	0.000
Smoke SO ₂ winter median	F =	31.050	1.971	7.075	4.311	7.089
	P =	0.000	0.055	0.000	0.000	0.000

Table 7.9 Significantly different pairs identified using the Scheffé test

	Sulphur Dioxide			
	winter median	yearly arithmetic mean	yearly median	yearly 98th percentile
Residential without smoke control	•△★	•△★	•△★	△★
Residential with smoke control				
Commercial without smoke control				
Commercial with smoke control	★○	★○	★○	★○
Residential/industrial without smoke control	•	•	•	
Residential/industrial with smoke control	△□	△□	△□	△□
Residential/commercial/ industrial without smoke control	○□	○□	○□	○□
Residential/commercial/ industrial with smoke control				

Symbols denote significantly different pairs at the 5% confidence limit.

of significantly different pairs are shown across all of the sulphur dioxide variables except that there is no significant difference between the residential/no smoke control and residential/industrial/no smoke control categories for the 98th percentile measures.

The Scheffé test does not identify any significant difference between the air pollution levels in area-types with the same land use classification but which are subject or not subject to smoke control. However, the land use classification does distinguish between areas not subject to smoke control.

Conclusions

The Scheffé test indicates that the variables land use and smoke control/no smoke control distinguish between area-types with significantly different air pollution levels but that the land use categories are more significant determinants of sulphur dioxide concentrations than whether an area is subject to smoke control.

The weakness of the smoke control/no smoke control variable as a predictor of sulphur dioxide concentrations is not surprising. As stated on Page 79 reduction of sulphur dioxide is not a stated aim of the smoke control provisions of the Clean Air Acts.

7.2.3 Tests Using Regression Analysis for the Two Dimensional Prediction Model

A regression analysis is performed on the data in the following axes of the air pollution prediction matrix:

- residential,
- commercial,
- residential/industrial and
- residential/commercial/industrial.

Each of the land use categories and the smoke, no smoke control predictors are binary dummy variables in the regression equation shown below (Equation 7.1).

$$P = B_0 + B_1.X_1 + B_2.X_2 + B_3.X_3 + B_4.X_4 + B_5.X_5 \quad (7.1)$$

Where:

- P = The measure of smoke or sulphur dioxide.
- B_0 = The equation constant.
- B_1 to B_5 = The coefficients of the binary dummy variables.
- X_1 to X_5 = The land use and smoke control binary dummy variables.

Assumptions

The assumptions underlying the regression analysis statistical technique are given in Section 6.2.6. It has already been established that the homogeneity of variance and normality assumptions are not satisfied for any of the transformations used on the smoke concentration data. However, the square root transformation produces the best homogeneity of variance and normality in the sulphur dioxide data. The regression analysis is therefore carried out on the square root of the measures of sulphur dioxide.

7.2.4 Results from the Regression Analyses

The results from the full regression analyses for these variables are given in Tables 7.10 to 7.13.

It can be seen that all of the variables make a significant contribution to explaining the variance in each of the sulphur dioxide variables at at least the 0.7% confidence level.

The standard error of estimate for each of the regression models in terms of $\mu\text{g}/\text{m}^3$ are as follows:

SO₂ Winter median of daily values SE = 2.28 $\mu\text{g}/\text{m}^3$

SO₂ Yearly arithmetic mean of daily values SE = 1.84 $\mu\text{g}/\text{m}^3$

SO₂ Yearly median of daily values SE = 1.84 $\mu\text{g}/\text{m}^3$

SO₂ Yearly 98th percentile of daily values SE = 4.36 $\mu\text{g}/\text{m}^3$

SE = Standard error of estimate

The results indicate that if an area is subject to smoke control measures the sulphur dioxide concentration will be approximately 0.4 $\mu\text{g}/\text{m}^3$ higher (winter median, yearly arithmetic mean and yearly median measures) or 0.7 $\mu\text{g}/\text{m}^3$ higher (yearly 98th percentile values) than areas which are not subject to smoke control measures. It has already been stated on Page 235 that average smoke concentrations in areas subject to smoke control are lower than in areas where there are no smoke control measures.

As discussed on Page 79 reduction in sulphur dioxide emissions was not a stated aim of the smoke control provisions of the Clean Air Acts, however reductions in sulphur emissions had been observed. A hypothetical explanation for the research findings is given below.

Smoke control orders are generally applied to the most polluted districts. These districts will generally have ambient sulphur dioxide concentrations which exceed the average concentrations observed for the land use type e.g. urban residential areas which have a very high density of houses/families per unit area. Reducing smoke emissions through smoke control orders results in an observed decrease in ambient sulphur dioxide concentrations but leaves a residual ambient concentration which still exceeds the average concentration for that land use category. This hypothesis is supported by the data presented in Table 3.4. A switch from bitumen coal to solid smokeless fuel will result in an approximate 85% reduction in smoke emissions (w/w) but only a 33% reduction in sulphur dioxide emissions (w/w). These percentages are increased if you take the calorific value of the fuel into account. The percentage of sulphur retained in the ash is very similar for domestic coal and smokeless fuels.

Table 7.10 Results from the regression analysis of the two dimensional prediction model for sulphur dioxide winter median of daily values - square root values

Multiple R 0.31383
R square 0.09849
Adjusted R square 0.09397
Standard error 1.51060

Variable	B	Standard error of B	Beta	T	Significance of T
Residential/commercial/industrial	0.886831	0.172473	0.233502	5.142	0.0000
Smoke control	0.455708	0.106301	0.135465	4.287	0.0000
Commercial	1.367678	0.255563	0.194513	5.352	0.0000
Residential/industrial	1.351139	0.175734	0.355754	7.689	0.0000
Residential	0.717545	0.163962	0.219287	4.376	0.0000
(Constant)	5.313028	0.138502		38.361	0.0000

Smoke control orders are applied to domestic, commercial and industrial sources of smoke but commercial and industrial sources can be exempted. Thus any reductions in sulphur emissions resulting from reducing coal use on domestic grates may be masked by emissions from exempted commercial and/or industrial sources.

Table 7.11 Results from the regression analysis of the two dimensional prediction model for sulphur dioxide yearly arithmetic mean of daily values - square root values

Multiple R	0.30187
R square	0.09113
Adjusted R square	0.08653
Standard error	1.35789

Variable	B	Standard error of B	Beta	T	Significance of T
Residential/commercial/industrial	0.659457	0.151184	0.193413	4.362	0.0000
Smoke control	0.427032	0.096972	0.141400	4.404	0.0000
Commercial	1.075352	0.230563	0.168614	4.664	0.0000
Residential/industrial	1.091710	0.155489	0.317058	7.021	0.0000
Residential	0.547791	0.143230	0.186879	3.825	0.0001
(Constant)	5.815708	0.119116		48.824	0.0000

Table 7.12 Results from the regression analysis of the two dimensional prediction model for sulphur dioxide yearly median of daily values - square root values

Multiple R	0.30038
R square	0.09023
Adjusted R square	0.08562
Standard error	1.35541

Variable	B	Standard error of B	Beta	T	Significance of T
Residential/commercial/industrial	0.711324	0.150907	0.209112	4.714	0.0000
Smoke control	0.400663	0.096794	0.132978	4.139	0.0000
Commercial	1.118683	0.230141	0.175817	4.861	0.0000
Residential/industrial	1.104134	0.155204	0.321414	7.114	0.0000
Residential	0.558728	0.142968	0.191055	3.908	0.0001
(Constant)	5.402395	0.118898		45.437	0.0000

Table 7.13 Results from the regression analysis of the two dimensional prediction model for sulphur dioxide yearly 98th percentile of daily values - square root values

Multiple R 0.27243
R square 0.07422
Adjusted R square 0.06953
Standard error 2.08905

Variable	B	Standard error of B	Beta	T	Significance of T
Residential/commercial/industrial	0.690595	0.232590	0.132874	2.969	0.0031
Smoke control	0.726889	0.149187	0.157897	4.872	0.0000
Commercial	1.201897	0.354711	0.123631	3.388	0.0007
Residential/industrial	1.335452	0.239212	0.254436	5.583	0.0000
Residential	0.662601	0.220353	0.148292	3.007	0.0027
(Constant)	9.417610	0.183254		51.391	0.0000

7.3 Testing of General Hypothesis 2 - Air

'That there may be regional variations in air pollutant levels not accounted for in the area-type classifications used in the proposed model'

A summary of the data in each of the regions by land-use and smoke control is given at the end of Appendix C.

The hypothesis is tested by plotting residuals from the multivariate regression model described in Section 7.2.3 against region and using both three-way analysis of variance techniques and multivariate linear regression analysis including regional constants.

7.3.1 Residual from Land Use/Smoke Control Regression Analysis Plotted Against Region

The studentised residuals from the regression equation described in Section 7.2.3 are shown in Figures 7.5 to 7.8 plotted against the ten United Kingdom regions identified in Figure 3.7. The numerical and letter symbols used to represent the numbers of values at a point are given below:

1 - 1	11 - B	21 - L	31 - V
2 - 2	12 - C	22 - M	32 - W
3 - 3	13 - D	23 - N	33 - X
4 - 4	14 - E	24 - O	34 - Y
5 - 5	15 - F	25 - P	35 - Z
6 - 6	16 - G	26 - Q	36 - *
7 - 7	17 - H	27 - R	
8 - 8	18 - I	28 - S	
9 - 9	19 - J	29 - T	
10 - A	20 - K	30 - U	

The regional symbols are as follows:

- 1 \equiv South East
- 2 \equiv Scotland
- 3 \equiv South West
- 4 \equiv North West
- 5 \equiv North East
- 6 \equiv N. Ireland
- 7 \equiv Midlands
- 8 \equiv Wales
- 9 \equiv East Anglia
- 10 \equiv London

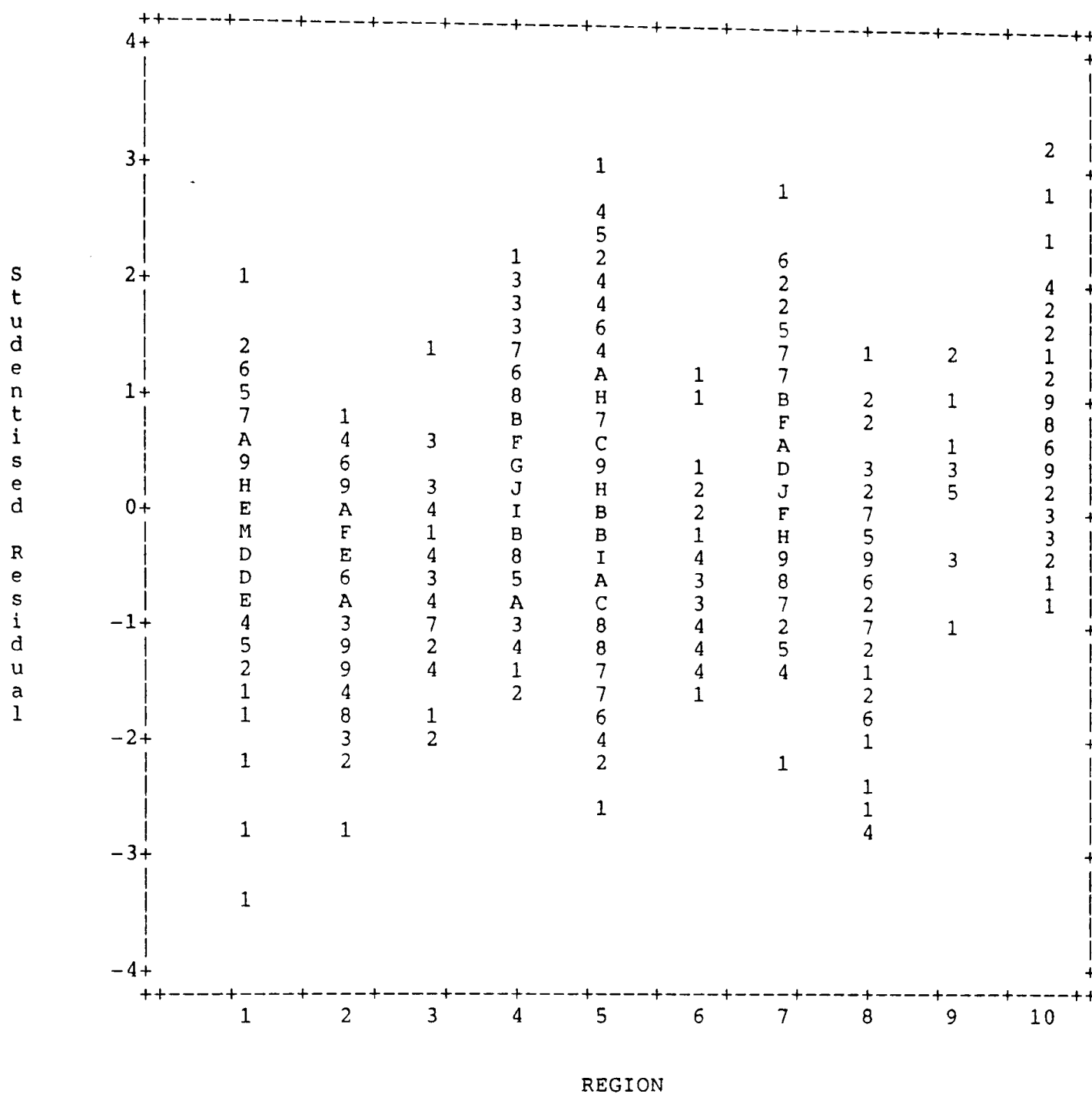
Visual assessment of these plots indicates that London and the North East have generally higher than average sulphur dioxide levels than is expected from the demographic variable used in the regression model. Also the average residual sulphur dioxide concentrations measured in Wales and Northern Ireland are slightly lower than in other regions.

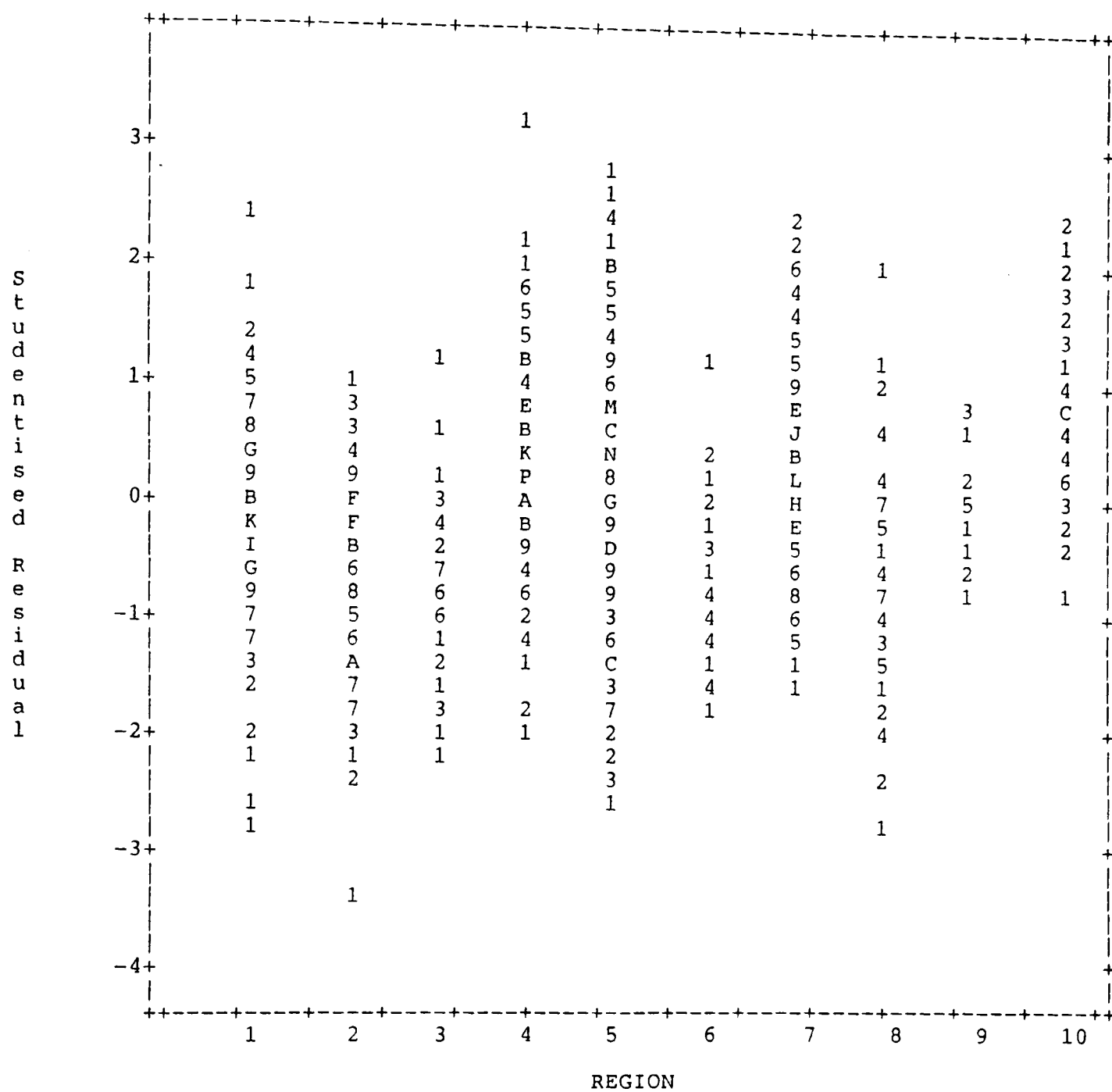
Perhaps the most obvious difference between the regions is that the South East, North East and Midland regions have a wide range of studentised residuals. The differences are likely to be, at least in part, due to the differences in the numbers of measurement sites in each of the regions.

This technique gives a convenient visual assessment of whether there are regional differences in sulphur dioxide concentration that are not explained by the land use and smoke control/no smoke control predictor variables but any assessment is only approximate. The following sections describe more rigorous methods of assessment using analysis of variance and multivariate regression analysis.

7.3.2 Regression Analysis

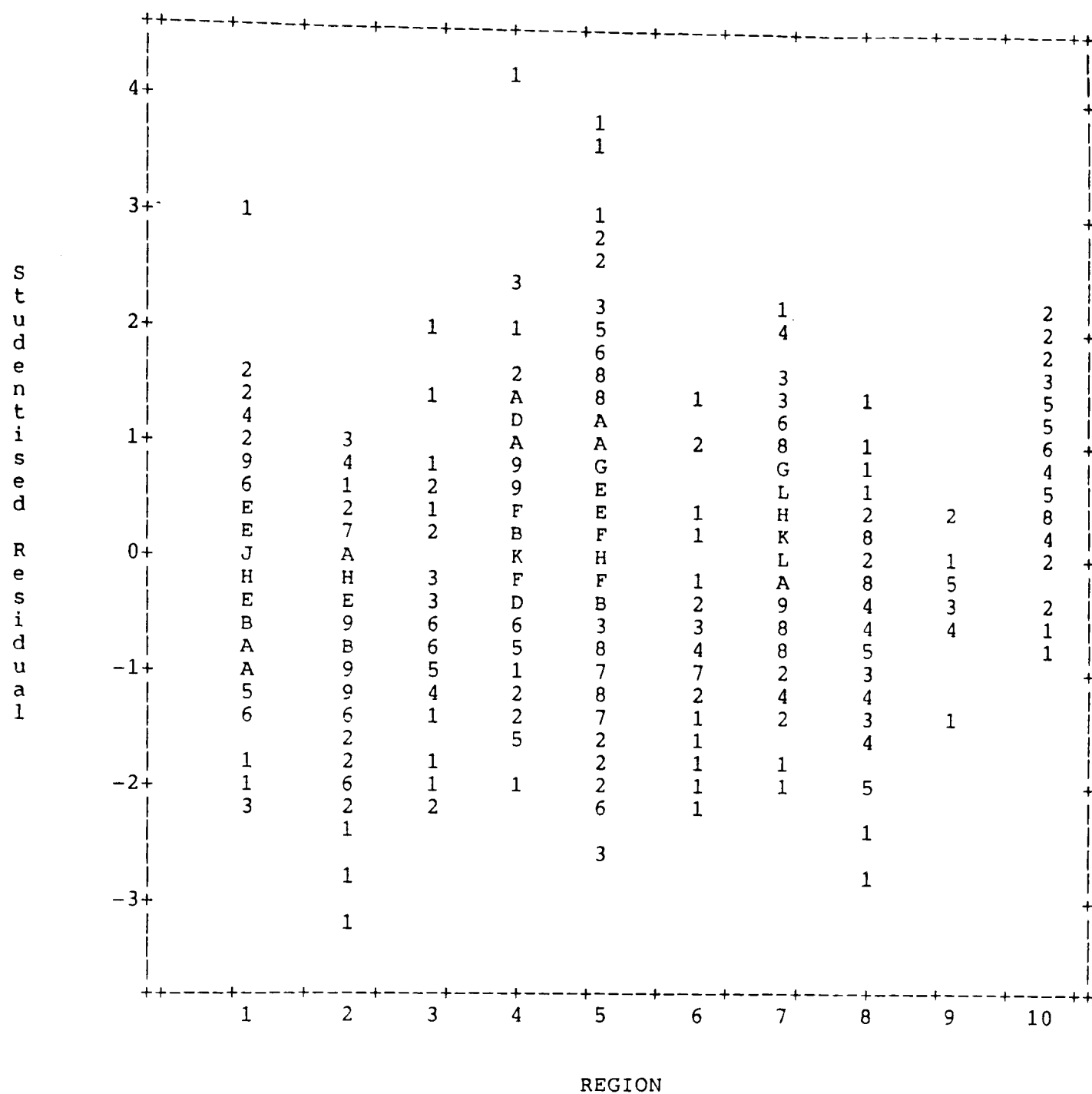
Regression analyses were carried out on data from the same land use categories as for the two-way analysis of variance described in Section 7.2.3. Each of the variables in the equation are binary dummy variables. However, Figures 7.5 to 7.8 show that the equality of variance assumptions for the





See pages 257 and 258 for 'number of values at a point' and region codes respectively.

Figure 7.6 Studentised residuals plotted against region - square root of sulphur dioxide yearly arithmetic mean of daily values



See pages 257 and 258 for 'number of values at a point' and region codes respectively.

Figure 7.8 Studentised residuals plotted against region - square root of sulphur dioxide yearly 98th percentile of daily values

regional groups will not be satisfied by the data. The East Anglia region has the most atypical distribution of residuals and is therefore excluded from the regression analysis.

Firstly the data are tested to determine whether the data from the different regions can be represented by 'parallel' regression models. This can be represented in two dimensions and for three regions only by Figure 6.3. Secondly the data are tested to determine whether the regional sets of data can be represented by a single regression line without separate regional coefficients (i.e. in Figure 6.3 $C_1 = C_2 = C_3$).

Test for 'Parallelism' in the Regional Regression Models

Two separate regression models are computed for each of the measures of sulphur dioxide. An F-test is performed on the residual sums of squares from each pair of regression models to determine whether the regional regression models are 'parallel'. Regional binary dummy variables are used in both sets of regression models.

The first set of regression models each have fifty-four equation variables. These fifty-four variables consist of the nine regional binary dummy variables and the product of each of these variables with each of the five demographic variables used in the previous regression modelling. These regression models contain independent regression models for each of the regions.

The second set of regression equations consist of the three 'parallel' regression models for the demographic variables but contain separate regional constants. These models have fourteen equation variables and no common equation constant. The fourteen variables are the nine regional binary dummy variables and the five demographic variables.

The results from the F-tests to determine whether the regional regression models are significantly 'non-parallel' are given in Table 7.14. The 5% confidence level for these degrees of freedom is 1.15.

These results show that the null hypothesis of no difference between the two sets of regression models (i.e. parallel regression models) can be accepted at the 99% confidence level.

Table 7.14 Test for 'parallel regional models - air pollution data

Measure of sulphur dioxide	F ratio	Degrees of freedom 1	Degrees of freedom 2
Winter median	1.0710	958	985
Yearly arithmetic mean	1.0799	948	975
Yearly median	1.0762	948	975
Yearly 98th percentile	1.0535	948	975

Test to determine whether the 'parallel' regional models are concordant - air pollution data

An F-test is performed on the residual sums of squares from the second set of regression equations used to test for parallel regional models and from a third set of regression models with no regional constants just a single equation constant. The third set of regression models is very similar to the models presented in Section 7.2.3 but exclude all data from the East Anglia region.

The F-test tests whether there is a significant difference between the regional constants in the parallel regional regression models.

The results from the F-test are given in Table 7.15. The 5% confidence level for these degrees of freedom is 1.15. The results show that there is no significant difference between the explanatory powers of the models with regional constants and the models with single equation constants.

It can be concluded that the regional classifications studied do not distinguish between variations in sulphur dioxide concentrations that are not already explained by the demographic variables: land use and and smoke control. However, there may still be regional variations in sulphur dioxide which could be identified by using different regional groups or explored by additional predictor variables such as coal consumption per capita etc.

Table 7.15 Test for significantly different regional constants - air pollution data

Measure of sulphur dioxide	F ratio	Degrees of freedom 1	Degrees of freedom 2
Winter median	1.0222	985	977
Yearly arithmetic mean	1.0664	975	967
Yearly median	1.0696	975	967
Yearly 98th percentile	1.0630	975	967

7.3.3 Three-way Analysis of Variance Tests

The cells of the three dimensional matrix, whose axes are defined by land use, smoke control and region, is only partially calibrated by the Warren Spring Laboratory air pollution data. As a result two sub-sets of the data have been abstracted so that a three-way analyses of variance tests can be performed on different parts of the matrix.

The sub-sets of the calibration data are:

Sub-set 1 - Data in the residential, residential/industrial and residential/commercial/industrial land use categories, either smoke controlled or non-smoke controlled from the North West, North East and Midland regions.

Sub-set 2 - Data in the residential, and residential/industrial land use categories either smoke controlled or non-smoke controlled from the Scottish, North West, North East and Midland regions.

7.3.4 Three-way Analysis of Variance - sub-set 1

The normality and homogeneity of variance assumptions underlying the analysis of variance test were tested using normal and detrended normal plots, and the Bartlett - Box F-tests and Cochran's C-tests of homogeneity. The un-transformed smoke data do not meet either of the homogeneity of variance assumptions. The un-transformed data for the yearly median values of sulphur dioxide meet the homogeneity of variance tests but do not satisfy the normality assumption.

A number of data transformation were therefore applied and the results from the Cochran's C-test and the Bartlett - Box F-test of homogeneity of variance are given in Tables 7.16 and 7.17.

It can be seen that the degree of homogeneity of variance for the yearly median values of sulphur dioxide are not improved by any of the data transformations, although the normality of the data is improved by the square-root transformation.

Table 7.16 Results from the Cochran's C-test of homogeneity

		Cochran's C-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke winter median	C =	0.1766	0.1373	0.1514	0.1463	0.1459
	P =	0.000	0.000	0.000	0.000	0.000
Smoke yearly arithmetic mean	C =	0.1595	0.1405	0.1497	0.1464	0.1369
	P =	0.000	0.000	0.000	0.000	0.001
Smoke yearly median	C =	0.1405	0.1228	0.1326	0.1294	0.1109
	P =	0.000	0.006	0.001	0.002	0.032
Smoke yearly 98th percentile	C =	0.1878	0.1251	0.1442	0.1321	0.1137
	P =	0.000	0.004	0.000	0.001	0.022
SO ₂ Winter median	C =	0.1004	0.1175	0.1054	0.1077	0.2340
	P =	0.126	0.013	0.067	0.049	0.000
SO ₂ Yearly arithmetic mean	C =	0.0889	0.1342	0.1010	0.1104	0.2535
	P =	0.492	0.001	0.117	0.034	0.000
SO ₂ Yearly median	C =	0.0912	0.1208	0.0973	0.0999	0.2420
	P =	0.379	0.008	0.186	0.134	0.000
SO ₂ Yearly 98th percentile	C =	0.1752	0.1794	0.1683	0.1699	0.2595
	P =	0.000	0.000	0.000	0.000	0.000

Table 7.17 Results from the Bartlett - Box F-test of homogeneity

		Bartlett - Box F-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke winter median	F = P =	11.2785 0.000	4.7466 0.000	7.2149 0.000	6.2098 0.000	5.0016 0.000
Smoke yearly arithmetic mean	F = P =	9.8372 0.000	4.4329 0.000	6.5290 0.000	5.6931 0.000	3.8036 0.000
Smoke yearly median	F = P =	8.5383 0.000	3.3019 0.000	5.2456 0.000	4.4438 0.000	3.6106 0.000
Smoke yearly 98th percentile	F = P =	8.2767 0.000	3.5018 0.000	5.3269 0.000	4.5937 0.000	3.2221 0.000
SO ₂ Winter median	F = P =	1.8695 0.016	3.2744 0.000	2.0386 0.007	2.3054 0.002	11.8352 0.000
SO ₂ Yearly arithmetic mean	F = P =	1.4925 0.087	3.5806 0.000	2.0802 0.006	2.4559 0.001	11.3872 0.000
SO ₂ Yearly median	F = P =	1.3815 0.134	3.4080 0.000	1.8913 0.014	2.2549 0.002	12.5944 0.000
SO ₂ Yearly 98th percentile	F = P =	4.1833 0.000	4.8409 0.000	3.9583 0.000	4.1191 0.000	11.1124 0.000

Analysis was therefore pursued using square-root transformations, recognising nevertheless the constraints on validity presented by the existence of heterogeneity of variance.

Figures 7.9 to 7.10 show the normal and detrended normal plots for the un-transformed and square-root transformations for the yearly median sulphur dioxide values.

7.3.5 Results from the Three-way Analysis of Variance Tests of Sub-set 1.

The results from the three-way analysis of variance tests for the un-transformed and square-root values of the yearly median concentrations of sulphur dioxide are shown in Table 7.18 to 7.20.

It can be seen that the null hypothesis that there is no relationship between these measures of sulphur dioxide and land use can be rejected at the 99.9% significance level.

The null hypothesis that there is no relationship between either the smoke/no smoke control or the regional classifications (North West, North East and Midlands) and these measures of sulphur dioxide cannot be rejected at the 95% significance level.

However, the null hypothesis for the interaction term between smoke/no smoke control and region can be rejected at the 99.9% level.

This indicates that the influence of smoke control cannot be distinguished from geographical region; degree of smoke control may therefore be an explanatory factor behind (and subsumed within) the observed inter-regional variations.

Identification of Significantly Different Pairs - Sub-set 1

A one-way analysis of variance test was carried out on the sulphur dioxide data in sub-set 1 followed by Scheffé tests to determine which pairs of area-type classifications have significantly different pollution levels (each area being classified according to land use, region and whether the area is subject to smoke control orders).

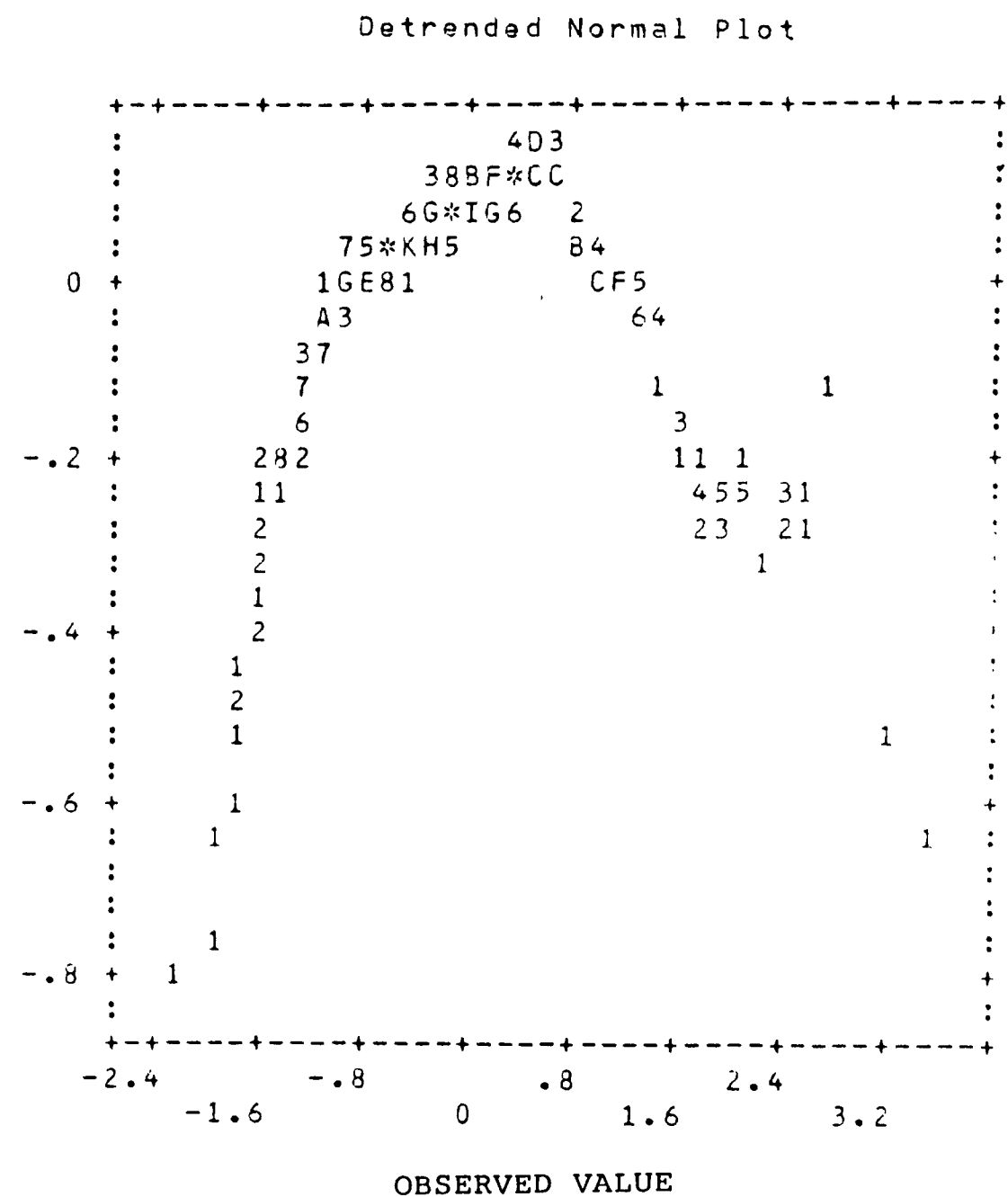
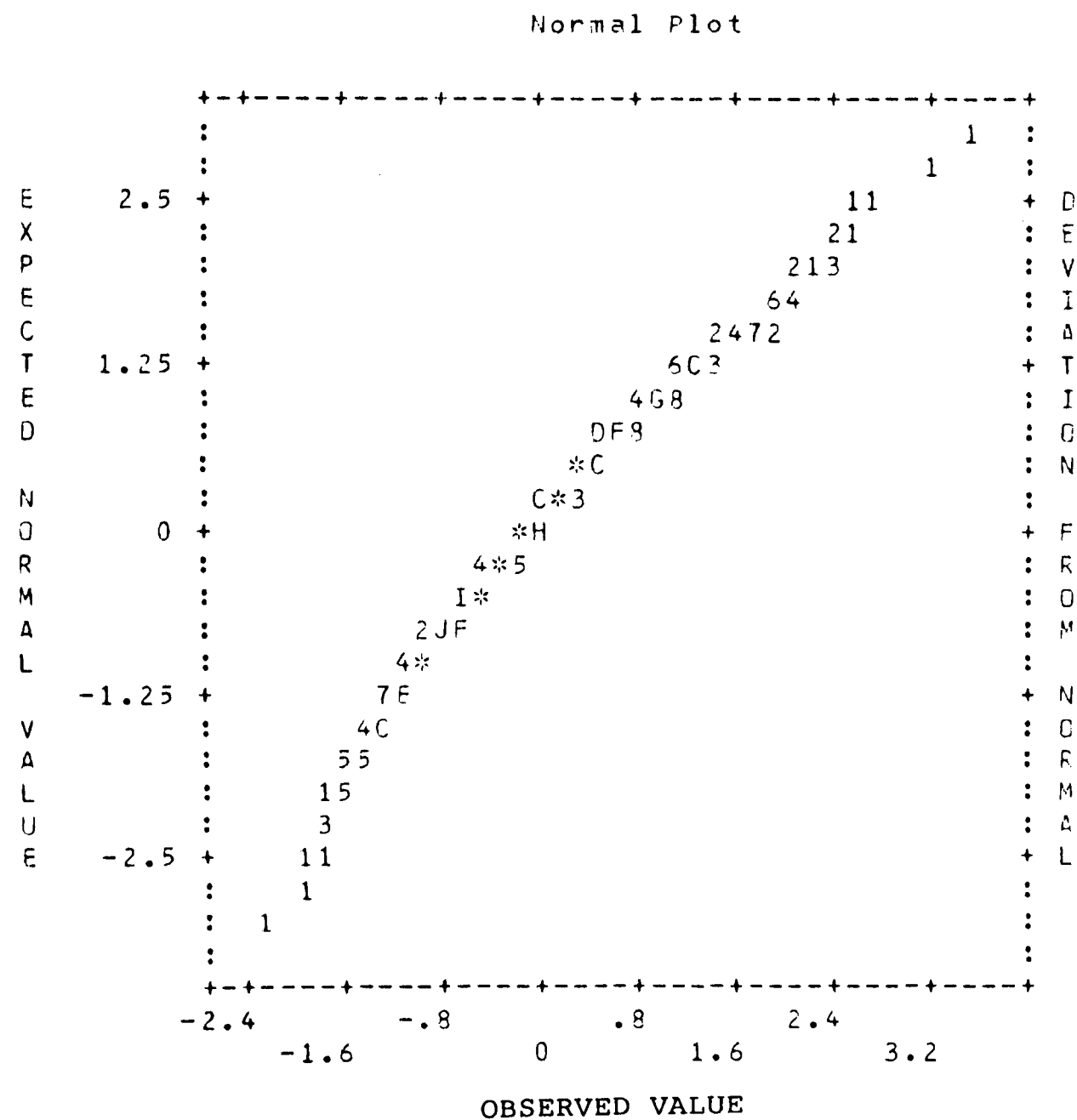


Figure 7.9 Normal and detrended normal plots for the sulphur dioxide yearly median of daily values - un-transformed

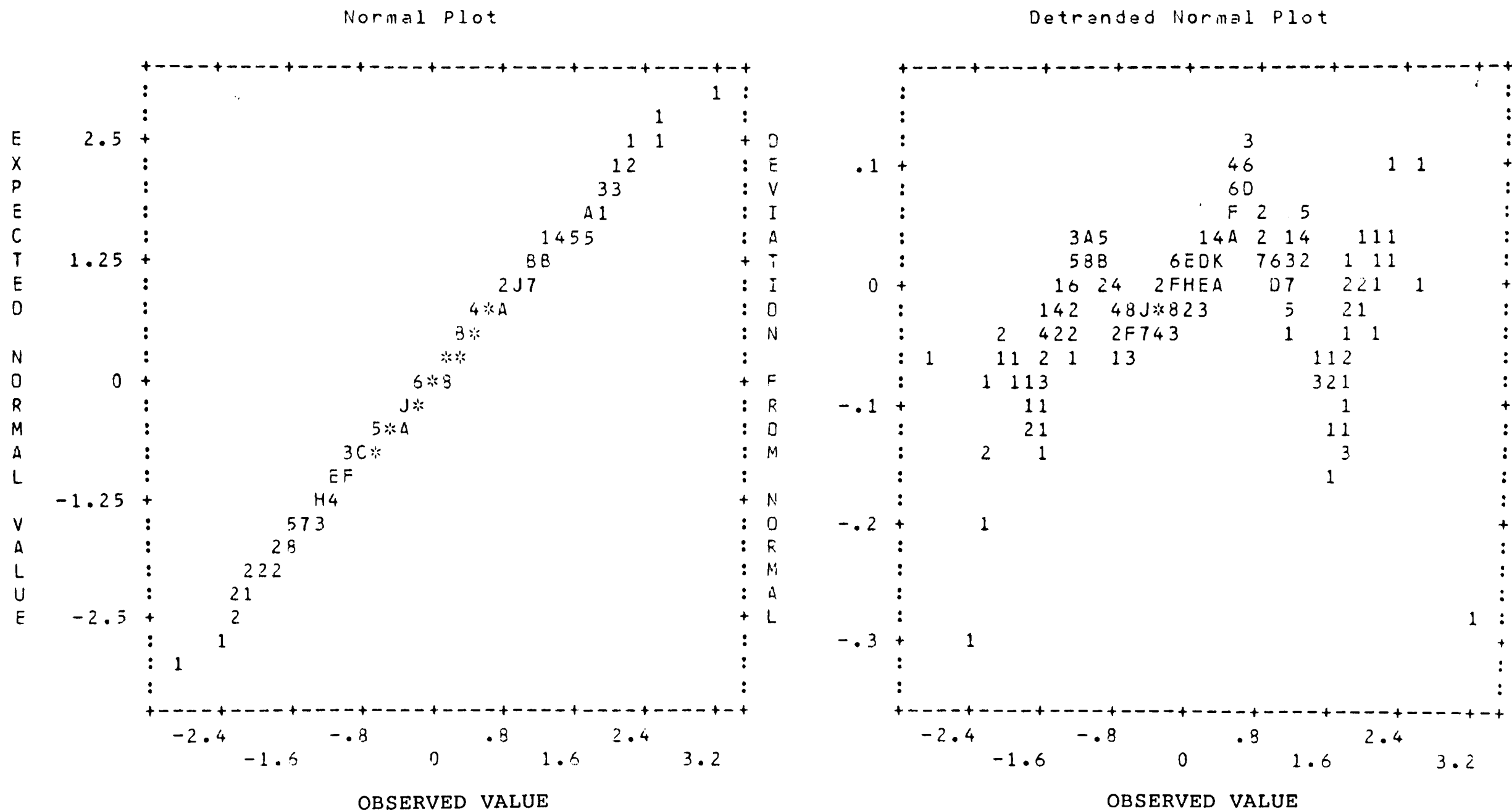


Figure 7.10 Normal and detrended normal plots for the sulphur dioxide yearly median of daily values - square-root

Table 7.18 Results from the three-way analysis of variance test for the square-root of sulphur dioxide winter median of daily values

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F ratio	Significance of F
Within cells	121870.01	429	284.08		
Land use	4924.78	2	2462.39	8.67	0.000
Smoke control	10.88	1	10.88	0.04	0.845
Region	1591.55	2	795.78	2.80	0.062
Land use by Smoke control	5.19	2	2.59	0.01	0.991
Land use by region	542.37	4	135.59	0.48	0.752
Smoke control by region	5487.94	2	2743.97	9.66	0.000
Land use by Smoke control by region	680.70	4	170.17	0.60	0.664

Table 7.19 Results from the three-way analysis of variance test for the square-root of sulphur dioxide yearly arithmetic mean of daily values

Source of variation	Sums of squares	Degrees of freedom	Mean squares	F ratio	Significance of F
Within cells	121806.83	429	283.93		
Land use	4919.68	2	2459.84	8.66	0.000
Smoke control	11.15	1	11.15	0.04	0.843
Region	1590.48	2	795.24	2.80	0.062
Land use by Smoke control	4.54	2	2.27	0.01	0.992
Land use by region	549.56	4	137.39	0.48	0.748
Smoke control by region	5463.60	2	2731.80	9.62	0.000
Land use by Smoke control by region	686.51	4	171.63	0.60	0.660

Table 7.20 Results from the three-way analysis of variance test for the square-root of sulphur dioxide yearly median of daily values

Source of variation	Sums of squares	Degrees of freedom	Mean squares	F ratio	Significance of F
Within cells	689.53	429	1.61		
Land use	32.49	2	16.24	10.11	0.000
Smoke control	0.05	1	0.05	0.03	0.861
Region	12.88	2	6.44	4.01	0.019
Land use by Smoke control	0.12	2	0.06	0.04	0.965
Land use by region	3.67	4	0.92	0.57	0.684
Smoke control by region	33.24	2	16.62	10.34	0.000
Land use by Smoke control by region	4.17	4	1.04	0.65	0.629

The Scheffé test only identified two pairs of area-type classifications which have significantly different levels of the winter median of daily values of sulphur dioxide. These are shown in Figure 7.21. There are no significantly different air pollution levels for any of the other pairs of area-types for any other measure of sulphur dioxide.

7.3.6 Conclusions

It is 99.9% certain that a statistically significant proportion of the observed variance in sulphur dioxide concentrations can be explained by variations in the land use categories:

- Residential
- Residential/Industrial
- Residential/Commercial/Industrial

where these observations are made in the North West, North East and Midland regions.

The smoke/no smoke control and regional classifications (NW, NE and Midlands) on their own do not group these values into significantly different groups. However, the smoke/no smoke control variables and regional classifications combined together do group the values into significantly different groups.

7.3.7 Three-way Analysis of Variance - Sub-set 2

The homogeneity of variance assumption is not met by any of the un-transformed measures of smoke or sulphur dioxide. A number of transformations were therefore applied to the data but the transformed data did not meet the homogeneity of variance assumption for sub-set 2. The results from the Cochran's C-tests and Bartlett-Box F-tests of the un-transformed and transformed values of measures of smoke and sulphur dioxide are given in Tables 7.22 and 7.23.

Table 7.21 Significantly different pairs identified using the Scheffé test for sulphur dioxide winter median of daily values - square root transformation

	No smoke control	Smoke control
Residential North West		
Residential North East		o●
Residential Midlands		
Residential/industrial North West		
Residential/industrial North East	o	
Residential/industrial Midlands		
Residential/commercial/ industrial North West		
Residential/commercial/ industrial North East	•	
Residential/commercial/ industrial Midlands		

Symbols denote significantly different pairs at the 5% confidence limit.

Table 7.22 Results from the Cochran's C-test of homogeneity

		Cochran's C-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke winter median	C =	0.2214	0.1404	0.1810	0.1675	0.3986
	P =	0.000	0.003	0.000	0.000	0.000
Smoke yearly arithmetic mean	C =	0.2160	0.1481	0.1822	0.1708	0.2733
	P =	0.000	0.001	0.000	0.000	0.000
Smoke yearly median	C =	0.1977	0.1324	0.1665	0.1553	0.2960
	P =	0.000	0.008	0.000	0.000	0.000
Smoke yearly 98th percentile	C =	0.1782	0.1299	0.1481	0.1384	0.2538
	P =	0.000	0.011	0.001	0.004	0.000
SO ₂ Winter median	C =	0.1285	0.1260	0.1260	0.1248	0.2424
	P =	0.014	0.019	0.019	0.022	0.000
SO ₂ Yearly arithmetic mean	C =	0.1141	0.1431	0.1174	0.1225	0.4509
	P =	0.083	0.002	0.056	0.030	0.000
SO ₂ Yearly median	C =	0.1179	0.1252	0.1153	0.1139	0.2524
	P =	0.052	0.021	0.072	0.085	0.000
SO ₂ Yearly 98th percentile	C =	0.2019	0.1662	0.1796	0.1744	0.2934
	P =	0.000	0.000	0.000	0.000	0.000

It can be seen that the homogeneity of variance assumption is not satisfied for any of the un-transformed or transformed data. No further analysis of sub-set 2 has been undertaken because of this constraint to the validity.

Table 7.23 Results from the Bartlett - Box F-test of homogeneity

		Barlett - Box F-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke winter median	F = P =	10.8876 0.000	4.9611 0.000	6.7114 0.000	5.8184 0.000	14.9064 0.000
Smoke yearly arithmetic mean	F = P =	9.8750 0.000	5.2023 0.000	6.5812 0.000	5.8820 0.000	11.5342 0.000
Smoke yearly median	F = P =	9.0314 0.000	3.8224 0.000	5.4280 0.000	4.6517 0.000	9.2242 0.000
Smoke yearly 98th percentile	F = P =	6.7887 0.000	3.9180 0.000	4.6278 0.000	4.2098 0.000	8.9731 0.000
SO ₂ Winter median	F = P =	3.1182 0.000	3.2717 0.000	2.2719 0.003	2.3683 0.002	13.9797 0.000
SO ₂ Yearly arithmetic mean	F = P =	2.6290 0.001	4.4471 0.000	2.6181 0.001	2.9747 0.000	19.7449 0.000
SO ₂ Yearly median	F = P =	2.4754 0.001	4.0736 0.000	2.3736 0.002	2.6976 0.000	17.0870 0.000
SO ₂ Yearly 98th percentile	F = P =	5.3166 0.000	5.0058 0.000	4.2058 0.000	4.2344 0.000	15.2194 0.000

7.4 Testing of General Hypothesis 3 - Air

'That there is a relationship between different measures of air pollution and that relationship will vary according to the area classification.'

The variable $\frac{\text{smoke}}{\text{SO}_2}$, where smoke and sulphur dioxide measure are both winter median daily values (October to March), is used to test whether there is a significant difference in the relative contribution of sources of smoke and sulphur dioxide in the different area-types and in the different regions of the United Kingdom.

This variable is of particular interest as differences in this ratio by either area classification and/or by region will indicate a difference in the contributory sources as discussed on Page 62. The concentrations of smoke at or near to ground level are largely affected by local burning of coal and diesel, whereas the local burning of coal and fuel oil will generally determine the concentrations of sulphur dioxide at or near ground level.

Keddie *et al.* (KED 78) states that the ratio of smoke to sulphur dioxide can be predicted using Equation 7.2 overleaf.

For the Forth Valley in Scotland:

$$R_1 = 3.15$$

$$R_2 = 0.32$$

$$R_3 = 0.02$$

Keddie *et al.* (KED 75 and KED 78) has shown that where the ratio of smoke to sulphur dioxide is:

- greater than 1, the local sources are predominately traffic and coal burning
- approximately equal to 1, then the local sources are predominately coal burning and
- less than 1, then commercial/industrial combustion of fuel oil is predominant.

$$R = \frac{R_1 + \beta R_2 + \alpha R_3}{1 + \alpha + \beta} \quad (7.2)$$

Where:

- R is the ratio $\frac{\text{smoke}}{SO_2}$,
- R_1 is the typical emission ratio of $\frac{\text{smoke}}{SO_2}$ for domestic coal,
- R_2 is the typical emission ratio of $\frac{\text{smoke}}{SO_2}$ for domestic solid fuel,
- R_3 is the typical emission ratio of $\frac{\text{smoke}}{SO_2}$ for commercial/industrial sources,
- β is the ratio between domestic coal and smokeless fuels to ground level sulphur dioxide concentrations and
- α is the ratio of the contribution of domestic coal and commercial/industrial coal and oil to ground level sulphur dioxide concentrations.

Figure 7.11 shows the distribution of the monitoring sites and their associated values of $\frac{\text{smoke}}{SO_2}$ throughout the United Kingdom (Northern Ireland is omitted from the plot due to practical problems when producing the map). Only nine sites have $\frac{\text{smoke}}{SO_2}$ which exceed 2.0. Five of these sites have very low winter median sulphur dioxide levels whilst the other four have high winter median smoke levels. Of the sites with high winter median smoke concentrations, two are in Belfast the others are in Bolsover and Middleborough.

General hypothesis 3 is tested using multivariate regression analysis and analysis of variance techniques.

7.4.1 Two-way Analysis of Variance

A two-way analysis of variance test and a multivariate regression analysis are carried out to determine whether there is any difference in the smoke/sulphur dioxide ratio in areas of different land use or smoke control. The analyses are performed on the data in the following land use axes of the air pollution prediction matrix:

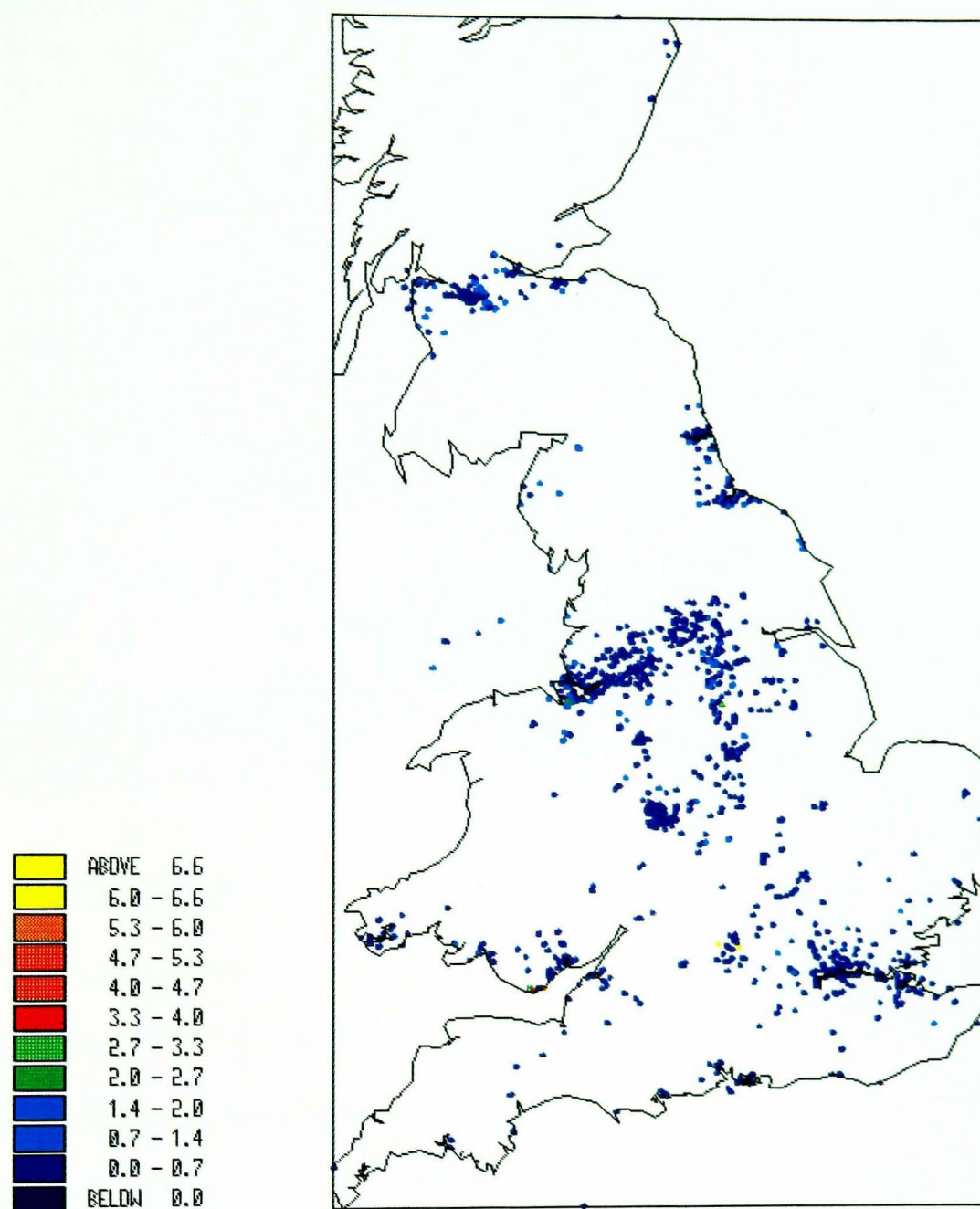


Figure 7.11 The ratio of smoke to sulphur dioxide at United Kingdom monitoring sites

Table 7.24 Results of the Cochran's C-test of homogeneity of variance - two-way analysis of variance.

		Cochran's C-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke/SO ₂ winter median	C =	0.4606	0.1849	0.2609	0.2247	0.2088
	P =	0.000	0.001	0.000	0.000	0.000

Table 7.25 Results of the Bartlett - Box F-test of homogeneity of variance two-way analysis of variance

		Bartlett - Box F-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke/SO ₂ winter medians	F =	53.7500	4.6816	14.7112	9.3449	12.8928
	P =	0.000	0.000	0.000	0.000	0.000

- Residential
- Commercial
- Residential/industrial
- Residential/commercial/industrial

The assumptions underlying the two-way analysis of variance technique were tested for the smoke/sulphur dioxide winter median data. It was found that the homogeneity of variance assumption was not met and a number of data transformations have been applied to the data to try to improve the homogeneity of variance. Tables 7.24 and 7.25 give the results from the Cochran's C-tests and Bartlett - Box F-tests of homogeneity of variance carried out on the data.

It can be seen that none of the data transformations meet the conditions of homogeneity of variance. However, the logarithmic transformation

appears to be the best approximation to these conditions as it minimises the values of C and F. The normal and detrended normal plots from this transformation are given in Figure 7.12.

It can be seen that there is also a marked deviation from normality.

The results from the two-way analysis of variance of the logarithmically transformed data are given in Table 7.26.

The results indicate that whether an area is subject to smoke control is 99.9% certain to explain a significant proportion of the the observed variance in the ratio $\frac{\text{smoke}}{\text{SO}_2}$. However, the land use categories, and smoke/no smoke control and land use combined, do not explain a significant proportion of the observed variance in this ratio even at the 59% confidence level.

As indicated on Pages 235 and 253:

1. smoke concentrations are lower than those found in areas not subject to smoke control
2. sulphur dioxide concentrations are higher in smoke controlled areas than in areas not subject to smoke control.

Thus areas subject to smoke control will have smaller values of the ratio $\frac{\text{smoke}}{\text{SO}_2}$ than areas which are not subject to smoke control. This difference is further quantified in the regression analysis in Section 7.4.2.

A one-way analysis of variance test was performed followed by a Scheffé test to identify pairs of area-types with significantly different ratios of smoke to sulphur dioxide. The significantly different pairs are given in Table 7.27. However, the residential/without smoke control group of data contains a very high value for $\frac{\text{smoke}}{\text{SO}_2}$ of 7.00 and thus the pair denoted by the symbol '•' may not be truly different except for this outlying value.

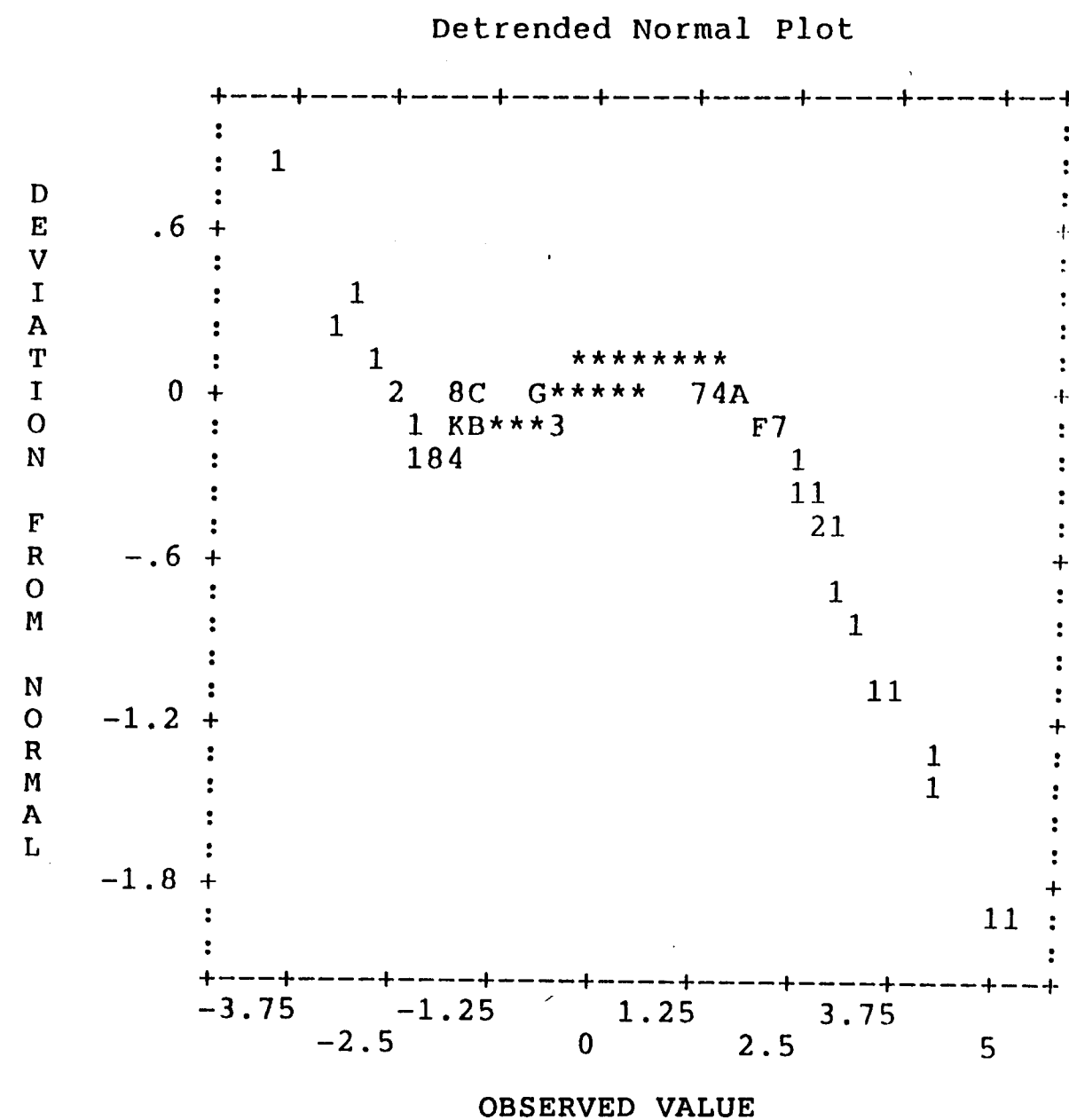
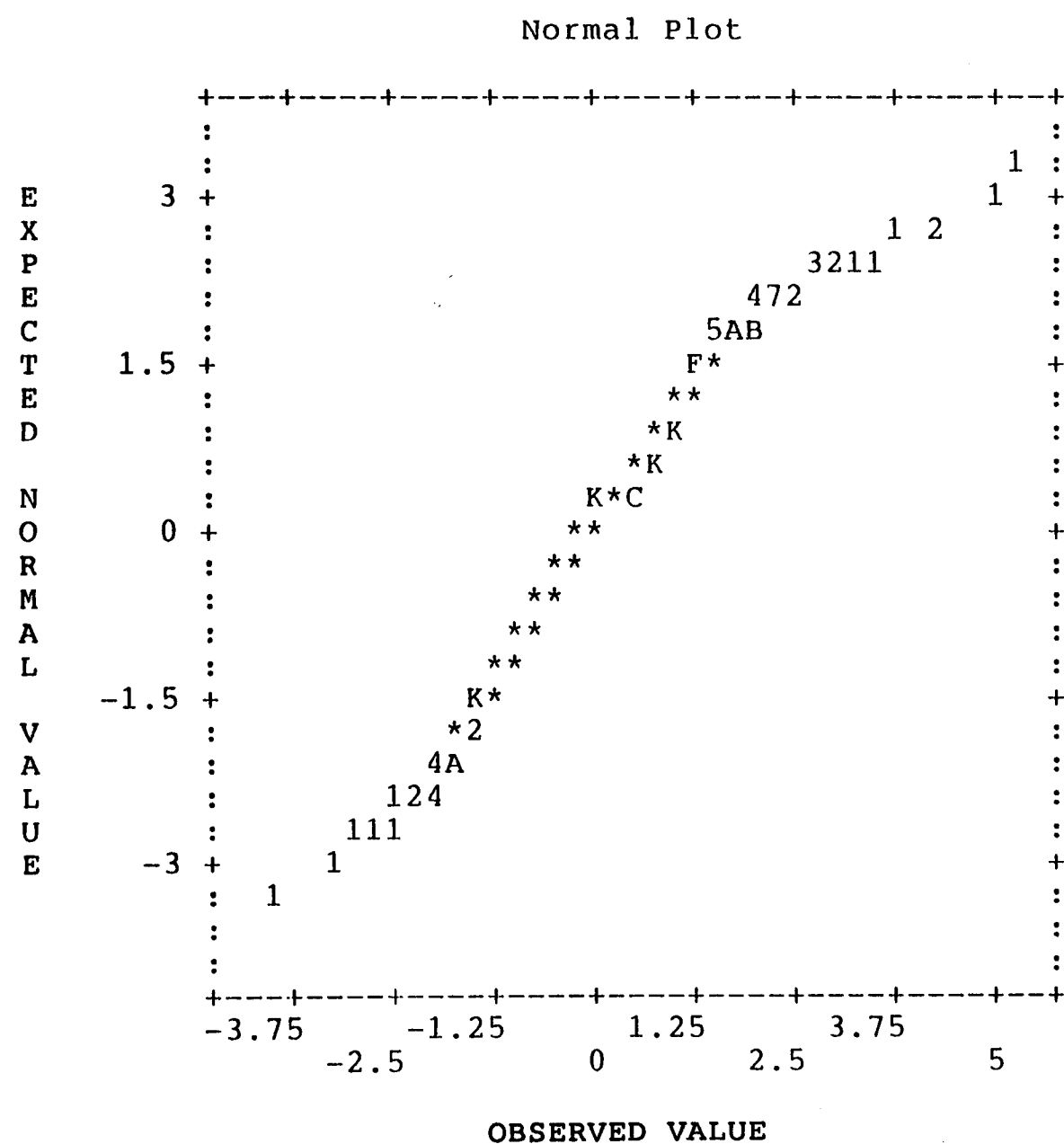


Figure 7.12 Normal and detrended normal plots for the ratio smoke to sulphur dioxide (winter median of daily values) - logarithmic transformation

Table 7.26 Results from the two-way analysis of variance testing of $\frac{\text{smoke}}{\text{SO}_2}$ - logarithmic transformation

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F ratio	Significance of F
Within cells	57.52	992	0.06		
Land use	0.11	3	0.04	0.65	0.586
Smoke control	0.66	1	0.66	11.37	0.001
Land use by smoke control	0.17	3	0.06	0.98	0.403

Table 7.27 Significantly different pairs identified using the Sheffé test - $\frac{\text{smoke}}{\text{SO}_2}$

Land use	Without smoke control	With smoke control
Residential	•	
Commercial		△
Residential/industrial	○ △	• ○
Residential/commercial/industrial		

7.4.2 Regression Analysis

A regression analysis was carried out using the logarithmic transformation of the $\frac{\text{smoke}}{\text{SO}_2}$ data. As previously discussed the normality and homogeneity assumptions are not wholly met by the data. However, the results of this analysis are given in Table 7.28.

The ratio of $\frac{\text{smoke}}{\text{SO}_2}$ is significantly related to the land use categories and whether an area is subject to smoke control. However, smoke control only accounts for a $0.09 \mu\text{g}/\text{m}^3$ decrease in this value. The ratios of $\frac{\text{smoke}}{\text{SO}_2}$ are higher in residential, and residential/industrial areas than in commercial areas. This is probably due to the importance of domestic smoke emissions on ambient ground level smoke concentrations in residential areas and the importance of emissions of sulphur dioxide from fuel use in commercial

Table 7.28 Results from the regression analysis of the two dimensional prediction model for $\frac{smoke}{SO_2}$ winter median values - logarithmic transformation

Multiple R	0.20798
R square	0.04326
Adjusted R square	0.03844
Standard error	0.23846

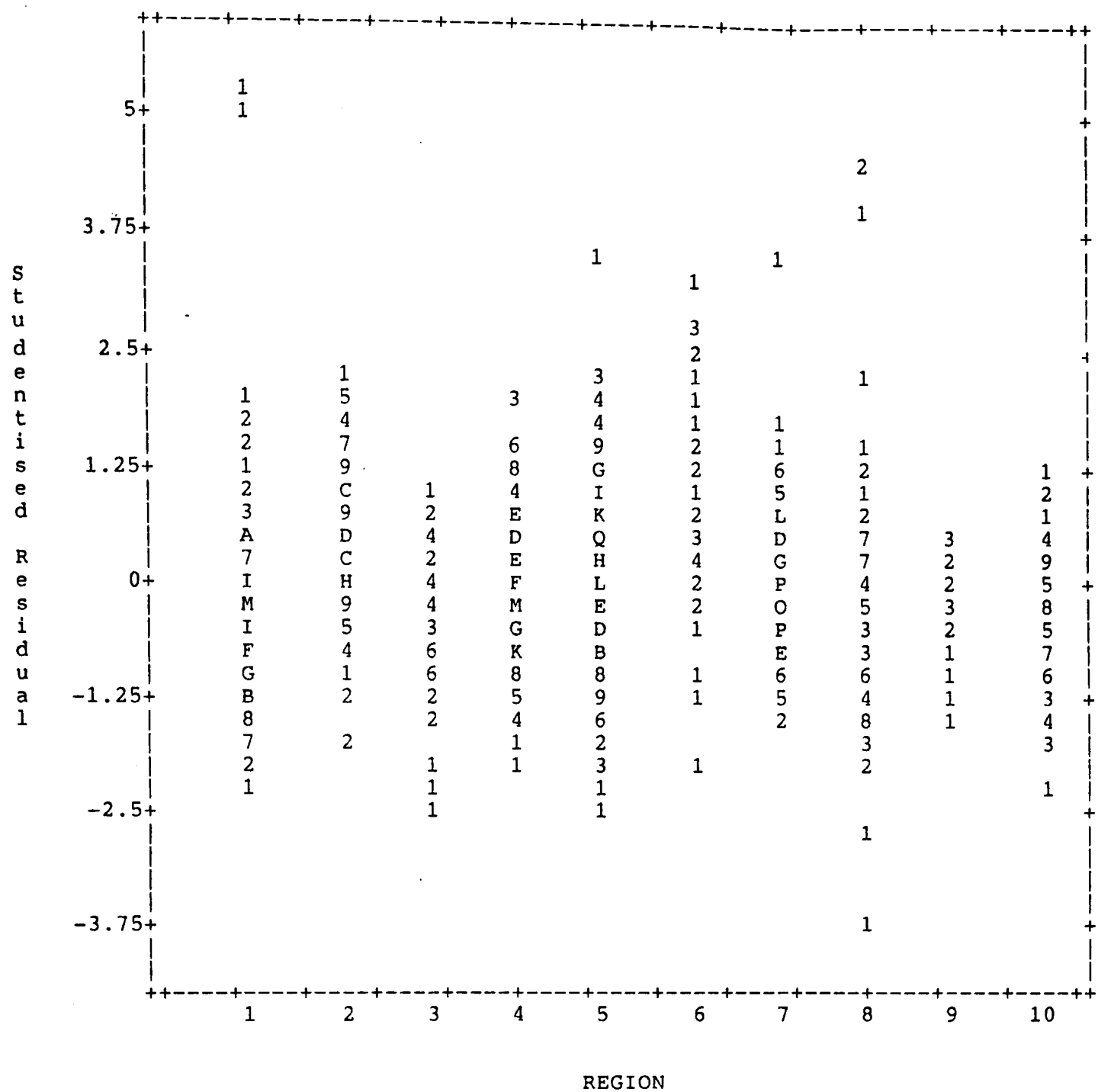
Variable	B	Standard error of B	Beta	T	Significance of T
Residential/commercial/industrial	0.107375	0.027451	0.184762	3.911	0.0001
Smoke control	-0.092188	0.016788	-0.179016	-5.491	0.0000
Commercial	0.090385	0.040494	0.084047	2.232	0.0258
Residential/industrial	0.125511	0.027961	0.215970	4.489	0.0000
Residential	0.116679	0.026131	0.232767	4.465	0.0000
(Constant)	-0.475663	0.022145		-21.480	0.0000

buildings.

7.4.3 Testing for Regional Variations in the Ratio of Smoke to Sulphur Dioxide

An indication of whether there are regional variations in the ratio $\frac{smoke}{SO_2}$ is given by the plot of the studentised residuals from the regression model described in Section 7.4.2 against region shown in Figure 7.13. The key to the regional numbers and the symbols used to indicate the number of values at a point are given on Pages 257 and 258.

The plot indicates that there may be significantly different ratios of $\frac{smoke}{SO_2}$ in the regions. The most noticeable difference is between the South West region and Northern Ireland. The plot also indicates that the homogeneity of variance assumption is not satisfied for the regression analysis in Section 7.4.3.



See Pages 257 and 258 for the 'number of values at a point' and regional codes respectively.

Figure 7.13 Studentised residuals plotted against region - logarithmic transformation of the ratio smoke to sulphur dioxide

Table 7.29 Test for parallel regional models for predicting the ratio smoke to sulphur dioxide

Variable	F ratio	Degrees of freedom 1	Degrees of freedom 2
$\frac{smoke}{SO_2}$	1.0420	981	954

Test for Regional Differences in the Ratio of Smoke to Sulphur Dioxide Using Regression Analysis

Regression analysis is used to test whether:

- the ratio $\frac{smoke}{SO_2}$ can be represented by parallel linear regression models, and
- the ratio $\frac{smoke}{SO_2}$ can be represented by concordant linear regression models.

The analysis is performed on data in the land use categories residential, commercial, residential/industrial and residential/commercial/industrial. The regression techniques and subsequent F-tests are described in Section 7.3.2.

The East Anglia region is excluded from the analysis due to the distribution of the residual air pollution levels being much narrower than in the other regions (see Figure 7.13).

The result from the F-test for 'parallel' regional models is given in Table 7.29. The 95% confidence level for these degrees of freedom is 1.15.

The results show that there is no significant difference between the 'parallel' regression models at the 95% confidence level. Thus, it is 95% certain that there is the same relationship between the demographic variables and the variable $\frac{smoke}{SO_2}$ in each of these regions.

The result from the F-test to determine whether there is any significant difference in the regional equation constants is given in Table 7.30. The 95% confidence level for these degrees of freedom is also 1.15.

Table 7.30 Test for significantly different regional equation constants for the ratio smoke to sulphur dioxide

Variable	F ratio	Degrees of freedom 1	Degrees of freedom 2
$\frac{\text{smoke}}{SO_2}$	1.0400	981	973

Thus the regression models presented in Section 7.4.2 is valid for all of the regions shown in Figure 3.7. However, data from the East Anglia region has not been included in the analysis and therefore may exhibit a different relationship.

There may be other regional characteristics which explain variations in the ratio $\frac{\text{smoke}}{SO_2}$ such as traffic density and concessionary coal use.

7.4.4 Three-way Analysis of Variance

The data in the subsets described in Section 7.3.3 are tested using three-way analysis of variance and regression analysis to determine whether there is any difference in the value of the smoke/sulphur dioxide ratio in different regions of the United Kingdom. The three-way analysis of variance also tests for differences in the ratio due to land use and smoke control but is limited to fewer land use classifications than in the two-way analysis of variance test.

The results from the Cochran's C-test and Bartlett - Box F-test of homogeneity of variance are shown for the un-transformed, \log_{10} , square-root, cube-root and inverse transformations in Tables 7.31 and 7.32 for sub-sets 1 and 2 respectively.

The data in sub-sets 1 and 2 are tested for homogeneity of variance. The un-transformed and transformed data analysed did not meet the homogeneity of variance assumption underlying the analysis of variance technique. However, the logarithmic transformation is the best as it minimises the C-test and F-test values. The normal and detrended normal plots of

Table 7.31 Results from the Cochran's C-test and Bartlett - Box F-test of homogeneity of variance for sub-set 1 data

		Cochran's C-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke/SO ₂ winter medians	C =	0.2254	0.1102	0.1165	0.1091	0.1484
	P =	0.000	0.035	0.015	0.041	0.000
		Bartlett - Box F-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke/SO ₂ winter medians	F =	8.6325	2.3907	3.9145	3.1444	4.1820
	P =	0.000	0.001	0.000	0.000	0.000

Table 7.32 Results from the Cochran's C-test and Bartlett - Box F-test of homogeneity of variance for sub-set 2 data

		Cochran's C-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke/SO ₂ winter medians	C =	0.1710	0.1367	0.1391	0.1356	0.1910
	P =	0.000	0.005	0.003	0.005	0.000
		Bartlett - Box F-test				
		un-transformed variable	log ₁₀ variable	square-root variable	cube-root variable	inverse variable
Smoke/SO ₂ winter medians	F =	6.2130	2.4306	3.4636	2.9531	4.5059
	P =	0.000	0.002	0.000	0.000	0.000

the logarithmically transformed data for subset 1 and subset 2 are given in Figures 7.14 and 7.15 respectively.

Again it can be seen that the normality assumption is not satisfied by the $\frac{smoke}{SO_2}$ data in either subset 1 or subset 2.

The results from the three-way analysis of variance tests of the logarithmically transformed data in subsets 1 and 2 are given in Tables 7.33 and 7.34.

It can be seen that for both sets of data the null hypothesis that there is no relationship between smoke control and the ratio $\frac{smoke}{SO_2}$ can be rejected at the 99.9% confidence level. However, the null hypothesis that there is no relationship between region and the ratio $\frac{smoke}{SO_2}$ can be accepted at the 7% confidence level for subset 1 and rejected at the 99.9% confidence level for subset 2.³ The null hypothesis that there is no relationship between land use and the ratio $\frac{smoke}{SO_2}$ can be accepted at the 83% and 71% confidence levels for subsets 1 and 2 respectively. There are no significant interaction effects between the demographic predictor variables for either subset.

³Subset 1 includes data from the additional land use category residential/commercial/industrial but does not include data from the Scottish region.

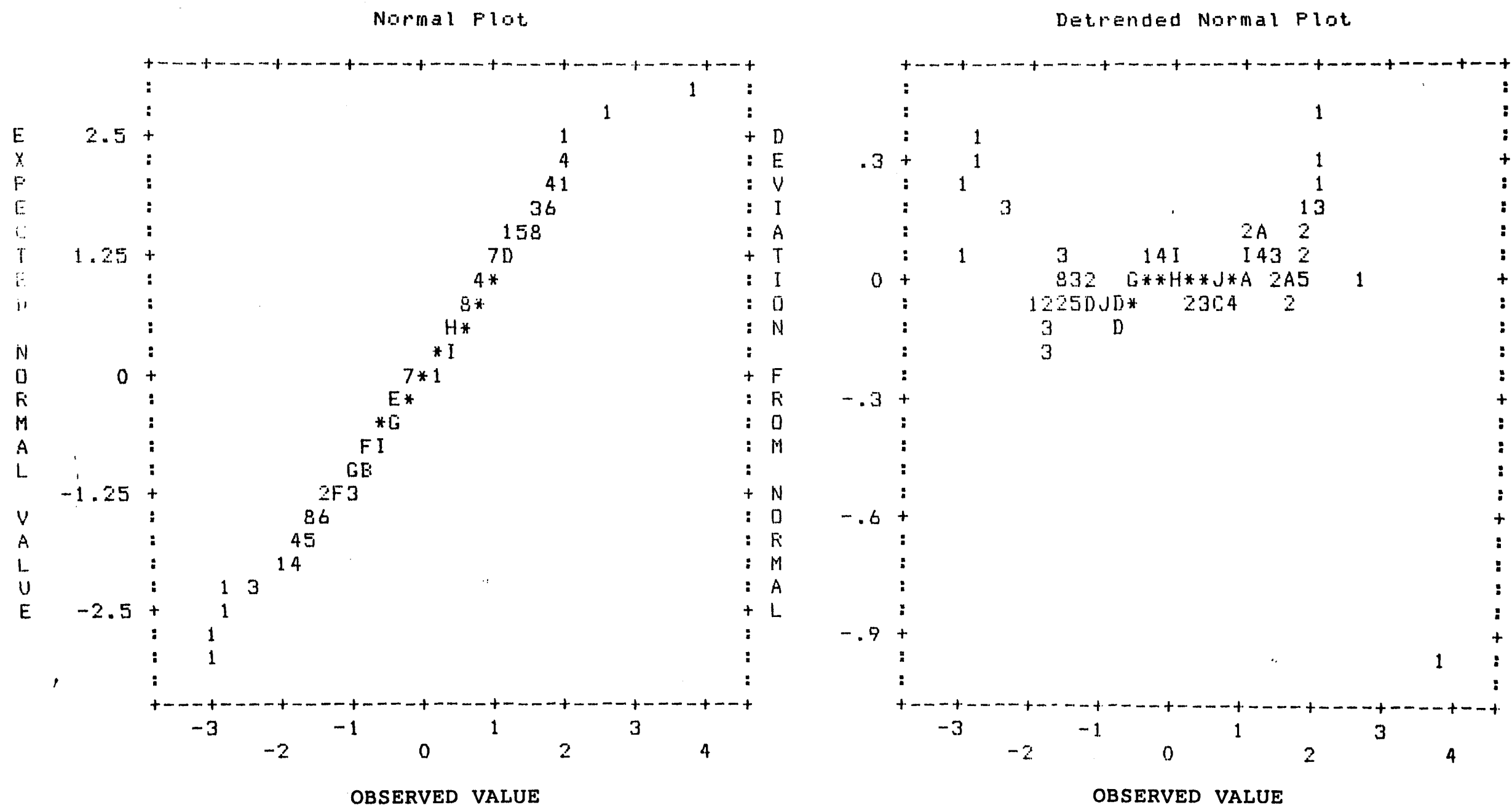


Figure 7.15 Subset 2 normal and detrended normal plots for the ratio smoke to sulphur dioxide (winter median of daily values) - logarithmic transformation

Table 7.33 Results from the three-way analysis of variance test of subset

1 - $\frac{\text{smoke}}{\text{SO}_2}$

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F ratio	Significance of F
Within cells	18.00	436	0.4		
Land use	0.15	2	0.07	1.77	0.172
Smoke control	1.56	1	1.56	37.78	0.000
Region	0.21	2	0.11	2.58	0.077
Land use by smoke control	0.01	2	0.00	0.09	0.916
Land use by region	0.12	4	0.03	0.72	0.577
Smoke control by region	0.14	2	0.07	1.67	0.190
Land use by smoke control by region	0.24	4	0.06	1.44	0.220

Table 7.34 Results from the three-way analysis of variance test of subset

2 - $\frac{\text{smoke}}{\text{SO}_2}$

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F ratio	Significance of F
Within cells	15.37	399	0.4		
Land use	0.04	1	0.04	1.13	0.289
Smoke control	1.29	1	1.29	33.41	0.000
Region	0.72	3	0.24	6.22	0.000
Land use by smoke control	0.00	1	0.00	0.00	0.973
Land use by region	0.15	3	0.05	1.33	0.263
Smoke control by region	0.03	3	0.01	0.29	0.833
Land use by smoke control by region	0.09	3	0.03	0.79	0.499

Chapter 8

Summary and Conclusions of Research and Scope for Further Work

8.1 Summary of Principal Findings

The research indicates that both sulphur dioxide air pollution and noise pollution are significantly associated with underlying demographic characteristics. The noise indices are related to industrial land use and traffic density and sulphur dioxide concentrations are associated with land use and whether an area is subject to smoke control. The research, although only a partial test of these associations, also indicates that area-based methods would provide a useful tool for the prediction of ambient environmental conditions on a national scale within the United Kingdom and that the demographic variables presented in the prediction models are robust at this scale.

There are some differences in noise levels in the regional classifications tested which are unexplained by the demographic variables included in the prediction models. These regional differences are most likely to be due to regional demographic variables which have not been tested as part of this research e.g. the percentage of heavy goods vehicles in traffic, daytime population density etc. The regional differences in noise levels in the three case study areas may be due to monthly variations in noise levels introduced by the sequential surveillance of the case study areas. No significant varia-

tions in sulphur dioxide concentrations have been identified, in the regional groups tested, which cannot be explained by the land use and smoke control demographic variables.

Further development of these models (possibly with the use of additional demographic predictor variables and with rigorously defined land use data) may provide national models for predicting sulphur dioxide and noise pollution within the United Kingdom which will satisfy the requirements outlined in Section 1.2.

The noise models present partial models for predicting average $L_{Aeq,5min}$, $L_{A10,5min}$ and $L_{A90,5min}$ noise levels on a national scale. The accuracy of these noise models on a regional or national scale is unknown due to:

1. difficulties in calculating the true standard error of estimate due to the type of data transformation employed and
2. the limited range of area-types used to develop the three case study area models.

The air pollution models have not been calibrated with land use data which relate to a defined spatial scale due to the land use classification system employed by Warren Spring Laboratory. Therefore the models application on a national scale is somewhat ambiguous. However, it is likely that the observers classifying the monitoring sites in terms of land use would adopt a spatial scale approximating to a circular 1 km² area around the measurement location. It is hypothesised that this spatial scale should be adopted for applying the air pollution prediction models.

The research indicates that the proposed sulphur dioxide prediction models' accuracy on a national scale are:

SO ₂ Winter median of daily values	SE = 2.28 µg/m ³
SO ₂ Yearly arithmetic mean of daily values	SE = 1.84 µg/m ³
SO ₂ Yearly median of daily values	SE = 1.84 µg/m ³
SO ₂ Yearly 98th percentile of daily values	SE = 4.36 µg/m ³
(SE = standard error)	

The research findings have implications for describing and predicting ambient environmental conditions in the United Kingdom. Area-based prediction methods are likely to provide a inexpensive method for:

1. spatially comprehensive mapping of ambient sulphur dioxide concentrations and noise pollution as input to 'state of the environment' reports,
2. identifying those area-types which are most likely to exceed the EEC directive guide and limit values for sulphur dioxide (80/779/EEC) which will help the targeting of pollution abatement measures.
3. characterising an area in terms of its likely noise levels or sulphur dioxide concentrations. This can be used as a planning tool to aid in the appropriate zoning of new developments. However, the difference between noise levels between area or traffic types is small compared with local differences.
4. establishing the typical noise levels or sulphur dioxide concentrations in an area-type which is affected by a pollution source so that the effect of that pollutant source can be estimated by comparison with the observed pollution levels.
5. forecasting future noise and sulphur dioxide concentrations as a result of a change in the demographic characteristics of an area.

The noise models presented in this thesis indicate that a method for predicting L_{A90} could be found that could replace the calculation method for L_{A90} which is presented in the British Standard BS4142. This alternative calculation method would be based on derived relationships between the underlying demography rather than subjective assessment as is indicated for for the derivation of the BS4142 calculation method. As a result the calculated noise levels should more accurately reflect actual noise levels and provide a better basis for judging the effect of industrial noise on mixed residential areas. The derivation and accuracy of the BS4142 are discussed on Pages 21 and 24 respectively.

The variability of noise or the ‘noise climate’ is also associated with the underlying demography of an area. The research has established that the traffic density variable is significantly associated with the variable $L_{A10} - L_{A90}$. If the findings of Griffiths *et al.* are valid (i.e. that public annoyance is related the $L_{A10} - L_{A90}$ value) then area based methods of noise prediction may provide a basis for predicting the likelihood of noise complaints.

8.2 Contribution to the Research Field

8.2.1 Noise Prediction

The research has established that:

- the basic concept of area-based noise prediction used by Wood *et al.* (WOO 74), Attenborough *et al.* (ATT 76a) and Pocock (POC 79) is robust in the three case study areas: Milton Keynes, West Midlands, the London Borough of Bexley and on a national scale and
- industrial land use and traffic density are probably the most important determinants of noise levels measured as L_{A10} , L_{A90} or L_{Aeq} in A-weighted decibels.

and has identified:

- a measure of traffic density which correlates with the L_{Aeq} , L_{A10} and L_{A90} noise levels (dB(A)) rather better than that used by Pocock (POC 79) in the area types studied.
- significant regional differences in noise levels that are not explained by traffic and land use alone.
- regression or matrix model specifications offer a potential for developing a national model for predicting L_{Aeq} , L_{A10} and L_{A90} noise levels (dB(A)) on the basis of further measurements.

- regression models and calibrated prediction matrices which provide partial indices appropriate to representing the typical noise climates of an area.

8.2.2 Air Pollution Prediction

The research has established that:

- the basic concept of area-based prediction of air pollution used by Wood *et al.* (WOO 74) and Pocock (POC 79) is robust in the United Kingdom,
- whether or not an area is subject to smoke control is an important determinant of the levels of sulphur dioxide and the ratio $\frac{\text{smoke}}{\text{SO}_2}$ (winter median of daily values) and
- land use is also an important determinant of sulphur dioxide concentrations.

The research has identified:

- regression or matrix model specifications that offer a potential for developing a national model for predicting the following measures of sulphur dioxide:
 - Winter median of daily values
 - Yearly arithmetic mean of daily values
 - Yearly median of daily values
 - Yearly 98th percentile of daily values
- regression models and calibrated prediction matrices which provide partial indices appropriate to representing the typical sulphur dioxide concentrations of an area and typical ratios of $\frac{\text{smoke}}{\text{SO}_2}$ of an area.

8.2.3 General Research Field

The research has established that:

- there is potential for developing area-based methods to predict land contamination,
- area-based methods are inappropriate to the prediction of river pollution although it may be possible to adopt a modified area-based prediction method for these pollutants (i.e. based on catchment areas) and
- the 1 km² square spatial unit is an appropriate scale for predicting L_{Aeq} , L_{A10} and L_{A90} in urban areas.

8.3 Scope for Further Work

The scope for further work can be categorised into:

1. further work that would represent a continuation of the research in this thesis and
2. further improvements in the gathering and storage of demographic data.

Each of these areas is discussed in the following sections.

8.3.1 Scope for Continuation of the Proposed Research

The current research could be extended by:

1. further calibration of pollution prediction models,
2. investigating other demographic characteristics as predictors of pollution,
3. development of models for predicting land pollution/contamination and other air pollutants and noise indices,

4. extending the noise pollution model to other time periods,
5. further investigation of regionality,
6. further investigation of the statistical properties of the air pollution data to identify the best data transformation and
7. further investigation of the standard error of estimate derived for the noise prediction models.

These avenues of research are considered in more detail in the following sections in the context of their theoretical and practical constraints.

8.3.2 Further Calibration of the Pollution Prediction Models

The further calibration of the pollution prediction models is limited by the pollution data available. The reduction in the number of air pollution monitoring sites in the National Survey of Smoke and Sulphur Dioxide monitoring network since 1982 has reduced the opportunity for model calibration. Prior to 1982 there were few changes in the monitoring locations between the different years. The changes that did occur were often due to a monitoring site becoming unavailable. An alternative location would be found nearby which would give air pollution measurements comparable with the original site. If further calibration of the air pollution model were to be undertaken including these alternative sites the results would be biased towards the air pollution characteristics for those areas with matched monitoring locations. Thus, there is little scope for further calibration of the air pollution model using data from additional monitoring sites collected during other years.

There may be further scope for calibrating the noise prediction model using two sources of data. The first opportunity may result from data collected as part of the forthcoming National Survey of Noise to be coordinated by the Building Research Establishment. The second opportunity would be to use data collected annually from the Open University undergraduate students studying the course T234 'Environmental Control and Public Health'. Each

year there is a fresh intake of students to the course who will take their noise measurements at new locations. The data from these students are currently coded and stored on computer disk. The central collection and coding of the data is currently funded by the Department of the Environment.

8.3.3 Further Investigation of Demographic Variables as Predictors

The paucity of demographic data which are currently available has placed severe constraints on this research. Many other demographic characteristics could perhaps be used to distinguish between different noise, smoke or sulphur dioxide levels.

The primary indicators which may provide improved prediction models are summarised below.

Noise Predictor Variables

Subdivision of the industrial land use category into categories which group industries according to their noise emissions may improve the noise prediction models. These industrial land use categories may vary between the different noise indices e.g. a drop hammer forge may effect local L_{Aeq} and L_{A10} noise indices but not the L_{A90} noise index because of its intermittent noise output.

Traffic could also be further categorised according to its average speed and the percentage of heavy goods vehicles.

Other factors which may influence L_{Aeq} , L_{A10} and L_{A90} noise levels are: the degree of land use segregation, the intensity of land use, noise abatement measures and topography. The intensity of land use may be partially represented by night-time population density in residential areas.

Predictors Variable Common to both Sulphur Dioxide and Smoke

A variable could be introduced which describes the atmospheric dispersion characteristics of the area. Such data could be as simple as the Pasquill

stability categories shown in Figure 3.2.

Land use data indicating the actual percentages of open space, residential, commercial and industrial land use, within a specified area, would provide a better basis for the development of the regression models for predicting smoke and sulphur dioxide. Warren Spring Laboratory could rapidly gather such data using remote sensing techniques such as aerial photography.

Land use categories such as residential land use could be subdivided to take account of the varying degrees of land use. The existing Warren Spring Laboratory land use classifications already distinguish between different residential land use densities. An alternative is to use a population density variable (in residential areas only). However, the introduction of further land use subdivisions will result in fewer data calibrating each cell of the prediction matrix.

Fuel consumption statistics for the area surrounding a site may also provide improved prediction models. Data relating to area sources rather than local point sources are likely to provide the best correlation because, although individual area source emissions are small in comparison to point source emissions, their larger number and poorer dispersion results in them making a disproportionate contribution to ambient smoke and sulphur dioxide concentrations.

Sulphur Dioxide Predictor Variables

The fuel consumption statistics suggested in the previous section should be combined with data relating to the sulphur content of fuels where these values vary between regions e.g. regional variations in the sulphur content of coals. This should take into account any specific controls on the sulphur content of fuels such as those described on Page 79.

It is likely that fuel oil, solid fuel and gas oil consumption will be well correlated with ambient sulphur dioxide concentrations (BAL 79).

Identification of an area's point sources of sulphur dioxide may help to explain variations in sulphur dioxide. Suggested industrial point sources are listed on Page 62. However, point sources may be masked by the dispropor-

tionate contributions made by area sources.

Smoke Predictor Variables

In urban areas the ambient smoke concentrations are likely to be correlated with traffic density and particularly the density of diesel vehicles within the area. It is also likely that domestic coal consumption is correlated with smoke concentrations found in residential areas during the winter months.

High 98th percentile smoke concentrations in rural areas may be caused by straw stubble burning. Therefore, the 98th percentile smoke concentration may be correlated with the percentage of land in the area which is used for cereal cultivation.

8.3.4 Prediction of Other Pollutants

The recent development of an inexpensive nitrogen dioxide monitoring method using diffusion tubes may result in large scale monitoring of nitrogen dioxide within the United Kingdom. However, the somewhat *ad hoc*. and uncoordinated approach used by the various groups and individuals carrying out the monitoring and the lack of associated demographic data may render this source of pollution data impractical for the development of area-based prediction methods.

Some of the larger scale nitrogen dioxide monitoring surveys may provide suitable data (e.g. the survey conducted by the Greater London Council). However, the simplicity and low cost of the measurement technique would also provide an excellent opportunity for conducting an air pollution study expressly for the purpose of developing an area-based prediction model for this pollutant. Nitrogen dioxide levels are also subject to a EEC directive (85/203/EEC) and is therefore a pollutant of considerable interest.¹.

A recent publication by Warren Spring Laboratory (WSL 88) describes their current air quality monitoring programs. They state that, when all of their monitoring sites are operational, they will be gathering data for:

¹Nitrogen dioxide diffusion tubes were not available as a monitoring technique until the later stages of this research.

- Acid deposition - 17 rural sites.
- Ozone -17 rural sites.
- Smoke and sulphur dioxide - 35 rural sites and 300 urban sites.
- Nitrogen dioxide - 6 sites in urban and industrial areas.
- Lead and other particulates - 13 sites.

Data from these monitoring networks will provide the most comprehensive source of air quality data within the United Kingdom.

The small number of sites which will be monitored in the future will place severe restriction on the development of area-based methods for predicting air pollutants other than smoke and sulphur dioxide in the United Kingdom.

The scope for developing area-based methods for use in the field of land contamination will depend upon the availability and comprehensiveness of historical land use data and upon the resources available for collecting these data and processing them. The model development although theoretically feasible may prove impractical on a national scale.

8.3.5 Extending the Noise Pollution Model to Other Time Periods

The proposed noise models are for the weekday time periods:

- 10am. to 4pm. (Three case study area data) and
- 6pm. to 10pm. (Student data).

These noise models could be extended to predict noise levels for other days or time periods. The variation in the noise levels that is attributable to the various land uses will vary considerably between different times of day. It may be necessary to use different land use categories which will reflect the relative time periods of operation. The traffic density variable will vary with time and may therefore be robust in predicting noise for all time periods.

8.3.6 Further Investigation of Regionality

The regional divisions selected for testing General Hypothesis 2, shown in Figure 3.7, are based on the statistical regions that are widely used to present demographic data and are themselves based upon administrative boundaries.

Further work could be carried out to determine whether different regional divisions would result in regional differences in air pollution which are unaccounted for by the underlying demographic characteristics. These alternative regional divisions could be based upon the stability frequency categories presented by Pasquill and shown in Figure 3.2.

Cluster analysis could be used to analyse the residuals from the two-dimensional matrix models or regression models and to determine whether there is any marked spatial pattern in the clusters of alike groups. The results from such an analysis may help to identify underlying demographic characteristics which are important determinants of the variations in air and/or noise pollution levels.

Any further research into regionality should ensure that sequential sampling techniques do not account for any regional differences found.

8.3.7 Data Transformations

The exponential transformations used in the multivariate regression analysis of the L_{Aeq} , L_{A10} and L_{A90} noise data has caused the usual method for determining the standard error of estimate for the resulting regression prediction models to be invalid. Further research to establish the correct standard errors for these models is beyond the scope of these present studies.

However, there are three methods which can be used to establish these standard errors of estimate. These methods are:

1. Examining the standard deviation of the residuals.
2. Using the 'Monte Carlo' method of risk assessment.
3. Using polynomial regression analysis.

The first method can be used to determine the standard error of estimate by equaling the standard error of estimate to ± 2 times the standard deviation of the residuals.

The second method, the Monte Carlo device, represents an alternative method of sampling whose main function is to provide solution of problems and development of models for which analytical solutions are either too involved mathematically or not readily available. The Monte Carlo method is a process of solving a problem by simulating original data with random-numbers. It uses the models that represent an image of reality and a table or graphs of the cumulative probability distribution of variables.

The third method is an alternative method for developing the prediction models assuming a polynomial relationship between the variables.

The best fit for predicting the variables L_{Aeq} , L_{A10} and L_{A90} will most probably be provided by polynomial regression based on the square values of the noise indices as cubic relationships or higher will produce a curve which would probably be too steep and therefore a poor fit to the data. This technique would hopefully remove the necessity for the use of data transformations and allow for the usual methods for computing the standard error of estimate.

It may be possible to derive a transformation to homogeneity for the data sets examined in Chapter 7 using the following technique.

The mean standard deviation is derived for each of the groups of measurements within the data subsets. The logarithm (base 10) of the standard deviation is then plotted against the logarithm of the mean of each group. Provided the graph is linear the data can be transformed to take out the dependence on the mean.

If the equation for the line is

$$\log M = A + B \log S \quad (8.1)$$

Where:

M is the Mean,

A is the intercept of the line and

B is the slope.

If the exponential is taken of both sides of the equation the result is:

$$M = e^A \times S^B \quad (8.2)$$

If the inverse is taken the transformation required can be identified by solving the equation:

$$T = \int \frac{1}{x}^{\frac{1}{B}} \quad (8.3)$$

Where:

T is the transformation to homogeneity,

B is the slope of the line of the graph

log M against log S for the
groups of data

M is the mean of the groups of data and

S is their standard deviation.

8.4 Recommendations for the National Pollution Data Base

Section 1.3 discusses the alternative methods for estimating pollution levels on a national scale. It also states that area-based methods should provide a convenient and cost effective method for predicting ambient environmental conditions if calibrated with demographic data that are readily available and spatially comprehensive.

The results from this research using the limited demographic and pollution data that are currently available presents a strong argument to support this statement. However, the development, calibration and use of area-based methods for predicting pollution on a national scale is currently restricted by the the lack and unconformity of demographic data available.

Much could be done to facilitate the development of our understanding of the relationships between demographic characteristics and pollution levels if a standardised method for collecting and storing demographic data were used. This will not only facilitate research in this field but also in other fields of research such as town, transport and resources planning.

Increasing computer storage of data should improve access and the manipulation of data provided the system of computer storage is carefully chosen for its flexibility and compatability with other systems and the data are collected at high resolution.

The use of computers in the fields of transport planning is already quite well advanced and therefore traffic flow data are already reasonably accessible. However, land use data are much less uniform in their presentation and characterisation as indicated by the land use data for the three case study areas discussed in Section 4.3.1. It is also important that the demographic data are for a defined spatial area. The Warren Spring Laboratory land use categories and their undefined spatial scale produced unnecessary restrictions on the development of the air pollution prediction model. However, the Greater London Council land use data, although somewhat dated, combined both flexibility and detail for a defined spatial scale and could be directly applied to the research.

The Warren Spring Laboratory data would be very much more useful if they contained more detailed statistics on the demography of a defined area around the monitoring site.

It is strongly recommended that the demographic data obtained for each of the monitoring stations should:

- relate to a specified area or specified areas around the monitoring site (e.g. 1 km² or 10 km²).
- be defined in terms of percentage area of different categories of land use, smoke control etc.
- include population density statistics.
- include fuel consumption statistics.

- include summary atmospheric dispersion characteristics.

Currently only night-time population densities are widely available. It would also be very useful to obtain daytime population statistics as this would give an indication of the degree of activity in areas other than residential areas.

The accuracy of the derived traffic density variable for the student data could potentially be improved by asking the Open University students to estimate the lengths of each road type identified in their questionnaire in the surrounding 1 km² square (see Figure A.5) these estimates could then be used to determine a more robust estimate of traffic density by assigning average vehicle flow rates to each of these road types. However, it may be too difficult for the students to make such an estimation. An alternative would be to ask the student to supply a grid reference or use the post-code. This information could then be used to locate the student's measurement site and the roads lengths in the surrounding 1 km² square could be measured from ordnance survey maps of the areas. The only practical method for determining the measurement locations from post-code data is by using a computer program.

References

- ATT 76a

Attenborough K., Clark S. and Utley W.A. 'Background noise levels in the United Kingdom', J Sound and Vibration 48 (3) pp 359-375, 1976.

- ATT 76b

Attenborough K. and Clark S. 'Towards a planning data base for community noise', Internoise 1976, pp 373-376, 1976.

- BAL 77

Ball D.J. and Hume R. 'The relative importance of vehicular and domestic emissions of dark smoke in Greater London in the mid 1970's. The significance of smoke shade measurements and an explanation of the relationship of smoke shade to gravimetric measurements of particulate.' Atmospheric Environment 11, pp 1065-1073, 1977.

- BAL 79

Ball D.J. and Radcliffe S.W. 'An inventory of sulphur dioxide emissions to London's air', Greater London Council, Research Report No 23, London, 1979.

- BAL 80

Ball D.J. and Armorgie C.J. 'Fuel use and sulphur dioxide emissions in central London in 1978/79', Greater London Council, Research Memorandum No. 566, London, 1980.

- BAL 83

Ball D.J. and Armorgie C.J. 'Implications for London of European air quality standards for sulphur dioxide and suspended particulates', Environmental Pollution (Series B), 5, pp 207-232, 1983.

- BEA 81

Beaman A.L. and Kingsbury R.W.S.M. 'Assessment of nuisance from deposited particulates using a simple and inexpensive measuring system', Clean Air, II (2), June 1981.

- BEN 76

Benarie M.M. 'Urban air pollution modelling without computers' U.S. Environmental Protection Agency EPA-600/4-76-055, N. Carolina, 1976.

- BER 74

Berry B.F. 'Equivalent values of traffic and industrial noise' National Physics Laboratory Acoustics Report AC 65, 1974.

- BOG 56

Bogue D.J. 'Metropolitan growth and the conversion of land to non-agricultural uses', Scripps Foundation, Oxford, Ohio, 1956.

- BOR 79

Borruso P. and Lyregaard P.E. 'Influence of averaging time in the measurement of road traffic noise', National Physics Laboratory Acoustics Report, AC91, May 1979.

- BRO 81

Broderson A.B., Edwards R.G., Hauser W.P. and Coakley W.S. 'Community noise in twenty Kentucky cities' Noise Control Engineering, 16, pp 52-63, 1981.

- BRO 89

Brooks J., Attenborough K. and Utley W.A. 'Student-based surveys of noise levels around and inside dwellings in the U.K.', *Journal of Sound and Vibration*, 132 (2), pp 317-330, 1989.

- BSI 62

British Standards Institute BS 3489, 'Sound level meters (industrial grade)', British Standards Institute, London, 1962.

- BSI 67

British Standards Institute BS 4142 'Method for rating industrial noise affecting mixed residential and industrial areas', London, 1967.

- BSI 69

British Standards Institute BS 1747, 'Methods for the measurement of air pollution', Part 2: Determination of concentration of suspended matter and Part 3: Determination of sulphur dioxide, London, 1969.

- BSI 81

British Standards Institute BS 5969: 1981/IEC 651, 'Specification for sound level meters', London, 1979.

- BSI 84

British Standards Institute BS 5228: 1984 , 'Code of practice for noise control on construction and demolition sites', London, 1984.

- BSI 86

British Standards Institute BS 6698: 1986/IEC 804, 'Specification for integrating-averaging sound level meters', London, 1986.

- BUC 71

Buchanan J. 'Evaluation of the housing stock and its environment', *Journal Of The Royal Town Planning Institute*, 57 (8), pp 372-375, 1971.

- BUC 73
 Buchanan J. 'Environmental quality of the housing stock and its environment', Journal of the Royal Town Planning Institute 57 (8) pp 372-375, 1975.
- CAL 71
 Calder K.L. 'A climatological model for multiple source urban air pollution.' , Proceedings of the 2nd. Meeting of the Expert Panel on Air Pollution Modelling, NATO Committee on the Challenges of Modern Society, Paris, France, July 26th-27th, 1971.
- COC 50
 Cochran W.G. and Cox G.M. 'Experimental designs', Wiley, New York, 1950.
- COL 71
 City of London 'Various Powers Act', Her Majesty's Stationary Office, London, 1971.
- CON 78
 Connor W.K. 'The behaviour of noise exposure variables in an urban noise survey sample', Noise Control Engineering 10, pp 14-21, 1978.
- CSO 72
 Central Statistical Office, 'Annual abstract of statistics', Her Majesty's Stationary Office, London, 1972.
- DEL 71
 Delany M.E., Copeland W.C. and Payne R.C. 'Propagation of traffic noise in typical urban situations' National Physics Laboratory Acoustics Report AC 54, 1971.
- DIX 81
 Dix H.M. 'Environmental pollution: atmosphere, land, water and noise', Wiley, 1981

- DOE 73

Department of the Environment, 'Planning and noise', Circular 10/73, Her Majesty's Stationary Office, London, 1973.

- DOE 75

Department of the Environment and Welsh Office 'The calculation of road traffic noise', Her Majesty's Stationary Office, 1975.

- DOT 71

Department of Trade and Industry, 'Digest of energy statistics 1971.' Her Majesty's Stationary Office, 1971.

- DOT 83

Department of Transport 'Manual of environmental assessment', Assessments policy and methods division, Department of Transport, London, 1983.

- DRA 87

Draxler R.R. 'Estimating emissions from air concentration measurements', Journal of the Air Pollution Control Association, 37 (6), pp 708-714, June, 1987.

- DRI 74

Driscoll D.A., Webster W.J., Haag F.G. and Farinacci J.W. 'Statistical correlates of the energy-equivalent sound level.' Journal of the Acoustic Society of America, 56 (4), pp 1297-1299, 1974.

- DUN 69

Dunn J.B. and Hutchins I.J. 'The distribution of traffic in Great Britain through the 24 hour of the day in 1968.' Road Research Laboratory Report LR 295, 1969.

- EPA 72
Environmental Protection Agency 'Compilation of air pollutant emission factors', Office of Air Programs Research, Triangle Park, North Carolina, U.S.A., 1972.
- ELD 75
Eldred K.M. 'Assessment of community noise', Journal of Sound and Vibration, 43 (2), pp 137-146, 1975.
- FID 78
Fidell S. 'Nationwide urban noise survey', J Acoustic Soc Am 64, pp 198-206, 1978.
- FOR 85
An Foras Forbatha, 'The state of the environment in Eire', Dublin, 1985.
- FOT 77
Fothergill L.C. 'The variation of environmental noise outside six dwellings between three seasons', Applied Acoustics, 10, pp 191-200, 1977.
- FRA 85
Frankish K.D. and Wallis A.D. 'Large scale automatic testing of L_{eq} meters', Proceedings of Internoise '85, pp 1291-1294, Munich, 18th - 20th September, 1985.
- GAR 67
Garnett A. 'Some climatological problems in urban geography with reference to air pollution', Transactions of the Institute of British Geographers 42, pp 21-44, 1967.
- GEB 72
Gebbrett L.F. 'The land use survey, 1966', Intelligence Unit, Dept of Planning and Transportation Research, Greater London Council, Report No 8, 1972.

- GIF 73

Gifford F.A. and Hanna S.R. 'Modelling urban air pollution', *Atmospheric Environment* 7, pp 131-136, 1973.

- GIL 73

Gilford C.L.S. and Norris C.A. 'The 1972 West Midlands noise survey', unpublished paper, Dept. of Construction and Environmental Health, University of Aston, 1973.

- GLA 75

Glaser E.R. and Kaunders R.M. 'Baseline community noise measurements of South West Philadelphia and Vicinity', *Proceedings of Inter-noise* 75, pp 441-444, 1975.

- GLA 79

Glaser E.R. and Silver C.A. 'The use of stratification to improve the design efficiency of community noise surveys', *J Acoustic Soc Am* 65, pp 1467-1473, 1979

- GLC 65

Greater London Council, Scientific Branch, 'Research into noise levels in London', (P.C.213, H.T.102, H.G.102 Ed 410) Planning and communications committee, housing committee, and education committee, London 1965.

- GRI 68

Griffiths I.D., and Langdon F.J. 'Subjective responses to road traffic noises', *Journal of Sound and Vibration* 8 (16), 1968.

- GRI 80

Griffiths I.D., Langdon F.J. and Swan M.A. 'Subjective effects of traffic noise exposure: reliability and seasonal effects', *Journal of Sound and Vibration*, 71, pp 227-240, 1980.

- HAR 77

Harland D.G. and Abbott P.G. 'Noise and road traffic outside homes in England', Transport and Road Research Laboratory, Laboratory Report LR 770, 1977.

- HIC-82

Hickman A.J. and Colwill D.M. 'The estimation of air pollution concentrations from road traffic', TRRL Laboratory Report 1052, Transport and Road Research Laboratory DOE/DOT 1982.

- HOL 67

Holzworth G.C. and Miller M.E. 'An atmospheric diffusion model for metropolitan areas', Air Pollution Control Association Journal, 17, pp 46-50, 1967.

- HOL 72

Holzworth G.C. 'Mixing heights, wind speeds, and potential for urban air pollution throughout the contiguous United States.' N.C: Environmental Protection Agency, Research Triangle Park, 1972.

- ISO 71

International Standards Office 'Assessment of noise with respect to community response', International Standards Organisation Recommendation, ISO/R 1996, 1971.

- ISO 82

International Standards Organisation ISO 1996/1-1982(E), first edition 1982-09-15, 'Acoustics-description and measurement of environmental noise, Part 1: Basic qualities and procedures', 1982.

- ISO 87

International Standards Organisation ISO 1996/2-1987(E), first edition 1987-04-15, 'Acoustics-description and measurement of environmental noise, Part 2: Acquisition of data pertinent to land use', 1987.

- KED 75

Keddie A.W.C., Roberts G.H. and Williams F.P. 'The application of numerical modelling to air pollution in the Forth Valley', Mathematical Models for Environmental Problems, Proceedings of the International Conference, Southampton University, Sept. 8th. - 12th., Editor Brebbia C.A., Pentack Press, London 1975.

- KED 78

Keddie A.W.C., Bower A.E., Maughan R.A., Roberts G.H. and Williams F.P. 'The measurement, assessment and prediction of air pollution in the Forth Valley - Final Report', Laboratory Report LR 279 (AP), Warren Spring Laboratory, Stevenage, 1978.

- KOS 62

Kosten C.W. and Van Os G.J. 'The control of noise', The National Physics Laboratory, Symposium No. 12, Her Majesty's Stationary Office, London, 1962.

- KUN 84

Kuno K., Zhang D., Ikegaka K. and Mishina Y. 'Study on noise environment of residence in urban areas', Internoise 1984, pp 954-958, 1984.

- KUR 71

Kurze U. and Beranek L.L. 'Sound propagation outdoors', In Noise and Vibration Control, Ed. L.L. Beranek, McGraw-Hill, New York, pp164-193, 1971.

- LAR 66

Larsen R.I. 'Determining source reductions needed to meet air quality standards', International Clean Air Congress, London, 1966.

- LEG 74

Legrand M. 'Statistical study of urban air pollution - sulphur dioxide and smoke', Statistical and Mathematical Aspects of Pollution Problems, Editor J.W. Pratt, Dekker, New York, 1974.

- MAN 76

Manser B.L. and Winders M.F. 'A survey of Brisbane's residential noise levels', National Conference Publication No 7619, The Institute of Engineers, Australia 1976.

- MAR 67

Marsh K.J. and Foster M.D. 'An experimental study of the dispersion of the emissions from chimneys in Reading - 1: the study of long term average concentrations of sulphur dioxide.' Atmospheric environment 1, pp 527, 1967.

- MEE 56

Meetham A.R. 'Atmospheric Pollution', Pergamon Press, London, 1956.

- MET 83

Meteorological Office, 'Observers Handbook', Her Majesty's Stationary Office, London, 1983.

- MCK 66

McKerrell A.C. and Hunt E.A. 'Noise annoyance in central London', Government Social Survey Unit, Her Majesty's Stationary Office, London, 1966.

- MIL 67

Miller M.E. and Holzworth G.C. 'An atmospheric diffusion model for urban areas', Journal of the American Pollution Control Association 17(1), pp 46-50, 1967.

- MOC 67

Mochizuki T. and Imaizumi N. 'City noises in Tokyo', J Acoustic Soc Japan 23, pp 146-159, 1967.

- MOH 68

Ministry of Housing and Local Government, 'Desk Atlas Maps.' 1968.

- MON 76

Montgomery T.L. *et al.* 'A simplified technique used to evaluate atmospheric dispersion of emissions from large power plants', in Power Generation - Air pollution monitoring and control, Editors. K.E Noll and W.T. Davis, Ann Arbor, Michigan, Ann Arbor Science Publishers Inc., 1976.

- MUR 78

Murray D.R., Samuel S.C. and Bow N.E. 'Use of a fluctuating plume puff model for the prediction of the impact of odour emissions' Proceedings of the 71st. annual meeting of Air Pollution Control Association, Paper 78-68.6, 1978.

- MYR 76

Myrup L.O. and Rogers D.L. 'The relationship between land-use and emission of automotive air pollution', International Journal of Environmental Studies, 8, pp 269-275, 1976.

- NAG 71

Noise Abatement Group, 'A community noise survey of Medford Massachusetts', Office of Noise Abatement, Department of Transport, Washington D.C., Department of Transportation, report DOT-TSC-OST-72, 1, 1971.

- NEL 87

Nelson P. (Ed.), 'Transportation noise reference book', Butterworths, London, 1987.

- OEC 64

Organisation for Economic Cooperation and Development, 'Methods for measuring air pollution', OECD, Paris, 1964.

- PAR 68

Parkin P.H., Purkis H.J., Stephenson R.J. and Schaffenberg B. 'London noise survey.' Building Research Station, Ministry of Public Buildings and Works, Her Majesty's Stationary Office, London, 1968.

- POC 79

Pocock R.L. 'The measurement and prediction of ambient environmental conditions in urban areas', Ph.D. Thesis, Aston University, 1979.

- POC 83

Pocock R.L. 'The prediction of ambient noise in urban areas', SERC research project GR/B/27327: Summary of findings, March 1983.

- PRA 78

Prabhu B.T. and Chakraborty R.L. 'An urban noise model for planners', Journal of Sound and Vibration 58 (4), pp 595-597, 1978.

- PRI 72

Price A.J. 'Community noise survey of Greater Vancouver', Journal of the Acoustic Society of America, 52, pp 488-492, 1972.

- RCE 76

Royal Commission on Environmental Pollution, 'Air pollution control: an integrated approach', Fifth Report, Her Majesty's Stationary Office, London, 1976.

- ROS 53

Rosenblith W.A., Stevens K.N. and Bolt Beranek and Newman Incorporated, 'Noise and man', in Handbook of Acoustic Noise Control, Volume 2, Ohio Wright-Patterson Air Force Base, Wright Air Development Centre, 1953.

- ROS 77

Rose J.W. and Cooper J.R. 'Technical data on fuel' Seventh Edition, The British Committee World Energy Conference, 1977.

- ROB 77

Robson A.J. 'The effect of urban structure on the concentration of pollution', Urban Studies 14, pp 89-93, 1977.

- SAF 73

Safeer H.B. 'Community noise levels - A statistical phenomenon', Journal of Sound and Vibration 26 (4), pp 489-502, 1973.

- SCH 53

Scheffé H.A. 'Method for judging all contrasts in the analysis of variance', Biometrika 40, pp 87-104, 1953.

- SEN 71

Senko A. and Kirshran P.V. 'Urban noise survey methodology', Goodfriend L.S. and Associates, Report 4-1262, New York, 1971.

- SMI 75

Smith F.B. and Jeffrey G.H. 'Airborne transport of sulphur dioxide from the U.K.', Atmospheric Environment, 9, pp 643-659, 1975.

- STE 55

Stevens K.N., Rosenblith W.A. and Bolt R.H. 'Noise Control', 1,1,63. 1955.

- TMG 76

Tokyo Metropolitan Government 'Tokyo fights pollution', revised edition, Research Institute for Environmental Protection, Tokyo Metropolitan Government, 1976.

- TUR 70

Turner D.B. 'Workbook of atmospheric dispersion estimates', Environmental Protection Agency, Research Triangle Park, North Carolina, Revised 1970.

- UTL 82

Utley W.A. 'Temporal sampling techniques for the measurement of environmental noise', Applied Acoustics 15, pp 191-203, 1982.

- WAR 88

Ward D. 'The Open University Survey of Noise Levels 1985 - 1987' Draft Report, Private communication 1988.

- WAT 82

Waterfield V.H. and Hickman, A.J. 'Estimating air pollution from road traffic: a graphical screening method', TRRL Supplementary Report No 752, Transport and Road Research Laboratory DOE/DOT 1982.

- WEA 64

Weatherley M.L.P.M. 'Measurement of atmospheric smoke and sulphur dioxide: reproducibility of results.' Warren Spring Laboratory, Report RR/AP/70, Stevenage, 1962.

- WEA 75

Weatherley M.L.P.M. 'Fuel consumption, smoke and sulphur dioxide emissions and concentrations, and grit and dust deposition in the U.K. up to 1973-4.' Report LR 214 (AD), Warren Spring Laboratory, Department of Trade and Industry, Stevenage, December 1975.

- WEE 85
Weeks, N. Personal communication, Milton Keynes Development corporation, 1985.
- WHO 80
World Health Organisation 'Analysing and Interpreting air monitoring data', Global Environmental Monitoring System, WHO Geneva. Offset publication No 51, 1980.
- WIL 63
Wilson A. (chairman), 'Noise -Final report', Committee on the Problem of Noise, Her Majesty's Stationary Office, London, 1963.
- WIL 79
Williams F.P. 'National survey of smoke and sulphur dioxide: Details of storage of summary data on magnetic tape', Warren Springs Laboratory, unpublished report No IR 408(AP), Dept. of Industry, 1979.
- WOO 74
Wood C.M., Lee N., Luker J.A. and Saunders P.J.W. 'The geography of pollution - a study of Greater Manchester', Manchester University Press, Manchester, 1974.
- WSL 66
Warren Spring Laboratory, 'National survey of smoke and sulphur dioxide - Instruction manual', Warren Spring Laboratory, Ministry of Technology, 1966.
- WSL 72
Warren Spring Laboratory 'National survey of air pollution 1961-1972' Volumes 1 to 5, Department of Industry, Her Majesty's Stationary Office, London, 1972.

- WSL 88

Warren Spring Laboratory 'Air quality monitoring' Air Pollution Division Leaflet Reference AP88B, Warren Spring Laboratory, Department of Industry, Stevenage, 1988.

Appendix A

Technical Considerations on Noise

A.1 Details of the Student Generated Noise Data

Noise measurements, taken by students studying the Open University Course T234 'Environmental Control and Public Health' (1985-86), were used as part of this research as described in Chapters 3 and 6.

This appendix summarises aspects of the measurement procedures, equipment, quality control and data processing associated with the student noise survey data. A brief outline of the student survey data is also given.

The manufacturer's tests and tests carried out by the Open University's staff and the students themselves are discussed in detail in papers by Frankish and Wallis (FRA 85) and by Brooks, Attenborough and Utley (BRO 89)

A.1.1 Measurement Instructions

The students are issued with precise written instructions on how to carry out the noise measurements in the T234 Home Experiment Book. Students also have the opportunity to view a demonstration of meter usage on two television programs associated with the course. Course tutors are available for consultation when necessary. The instruction associated with the home experiments is backed by comprehensive teaching texts on noise. Three of the course's sixteen teaching texts are devoted to noise and cover the concepts and terminology, fundamentals of noise control, noise assessment, standards and legislation.

The student noise measurements used in this research are derived from the results reported by students completing the compulsory noise experiment. The instructions for this experiment are reproduced in Figure A.2.

A.1.2 Reporting of Data by Students

Assignment Booklet 4 included results summary sheets which are completed by the students.

The report forms are primarily designed to present the data required by the tutors. However, some additional questions were added so that the student's results

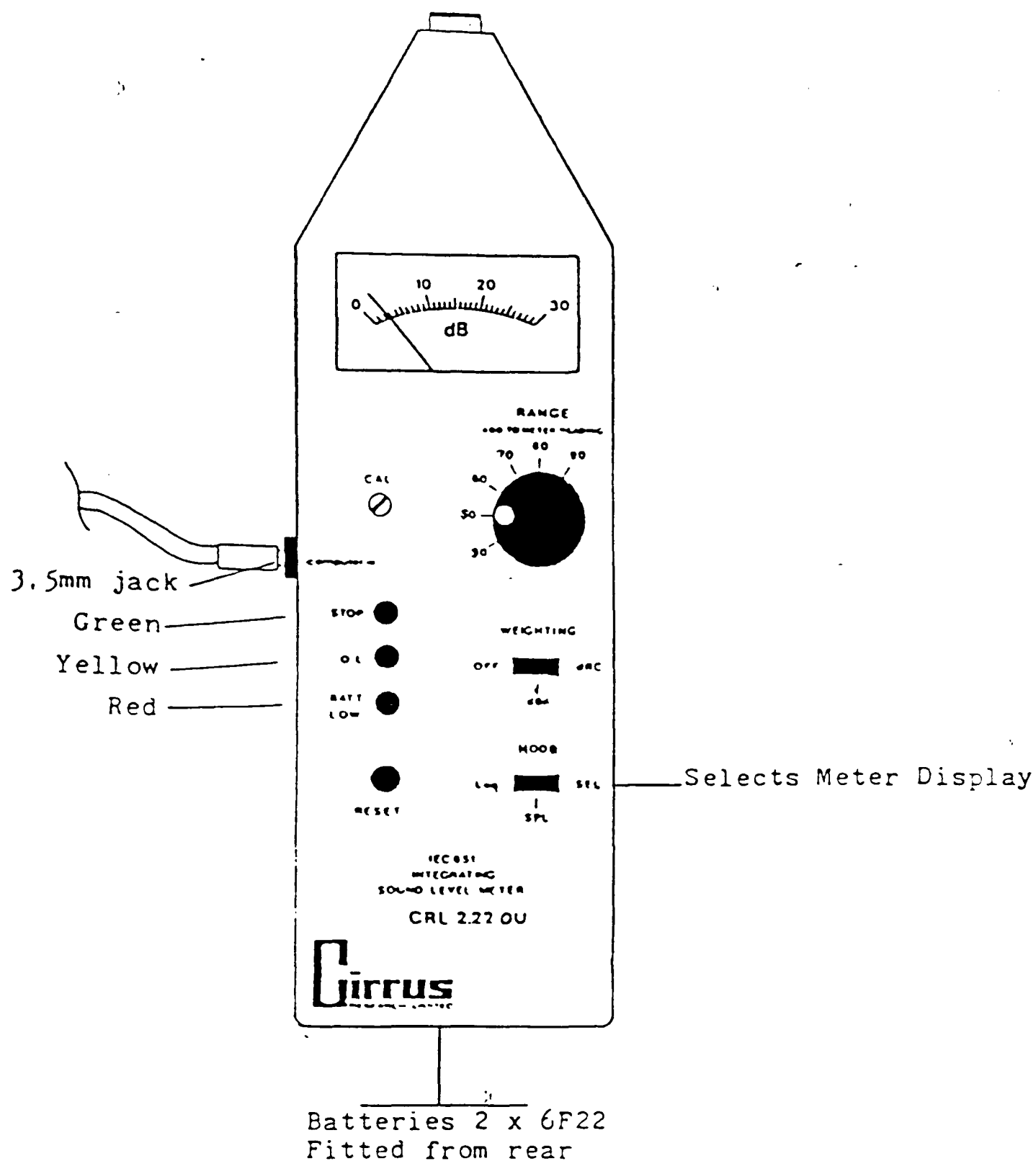


Figure A.1 The BS 5969 sound level meter used by Open University students in their home experiments

Comparison of three noise indices for characterising unsteady ambient noise levels

Aims

- 1 To gain practical experience of the use of the HEK sound level meter outdoors for measuring unsteady noise levels.
- 2 To reinforce understanding of the differences between L_{90} , L_{10} , and L_{∞} and of the meaning of percentile levels.
- 3 To stimulate consideration of the relative merits of L_{10} or L_{∞} in dB(A) for characterising unsteady noise levels.

Theory

Unit 11, Section 5.

Method

- 1 After familiarising yourself with the controls on the HEK SLM using Audio-cassette 3 and after reading through the sections on the sound level meter in this Home Experiment Book, and listening to Band 3 of Audio-cassette 3, take up a measuring position outside the **front** of your home, if possible on a windless weekday evening. The position should be such that, with your back to the building and with the sound level meter pointing away from the building (and you) the microphone is 1 m away from the building and just over 1 m from the ground, i.e. at about waist height. This position is recommended since a microphone position 1.2 m above the ground and 1 m from the noise-exposed facade corresponds to the standard position used in monitoring the noise exposure of dwellings.
- 2 Fit the windshield over the microphone on the sound level meter. Make a note of the time on your results summary sheet. Adjust the RANGE switch to an appropriate value. Make sure that the WEIGHTING switch is set to A-weighting and the MODE switch to SPL. If possible try to avoid having to change RANGE to follow the varying sound level. Note the time and press RESET gently.
Spot-readings should be made, as directed in Band 3 of Audio-cassette 3, regularly, every few seconds, attempting to give the instantaneous reading of the meter needle on each occasion. If you are able to make a reading every 3 seconds then the total length of time for 100 spot-readings will be 300 seconds, which is 5 minutes. In any case note the length of time for which you have been measuring and record this on the results summary sheet in the assignment book. It will now be necessary to obtain the L_{∞} reading for the same period. Fortunately your sound level meter has measured this automatically as long as the RANGE has not been changed.
- 3 Slide the MODE switch gently to L_{∞} and note down the reading on the results summary sheet. If you found it necessary to change RANGE during your spot readings then it will be necessary to make an L_{∞} measurement over a separate period equal in length to your total spot reading period. Set the RANGE switch so that peak levels are registered by the meter needle. Slide the MODE switch to L_{∞} , press RESET gently and record the L_{∞} value on the results summary sheet after the appropriate period.
- 4 Note any contributing noise sources and the major noise contributor as appropriate on the results summary sheet.
- 5 Make representative measurements of the peak noise levels in dB(A) with the MODE switch in the SPL position adjusting the RANGE switch as necessary and with both A- and C-WEIGHTING and complete the remaining entries requested on the results summary sheet. As long as the peak levels differ by less than 8 dB(A) then it will be sufficient to take the arithmetic average.

In TMA 04 you will be asked to write a report (see Section 3) on these measurements and to answer questions that probe your interpretation and understanding of your data.

Figure A.2 Compulsory Noise Experiment instructions

could be used as part of this and other research. The Assignment Booklet was designed jointly by the course team, the Department of the Environment, Dr. Brooks and I. Advice on the result sheet design was given by Dr. Utley of the Building Research Establishment.

The results summary sheets are reproduced in Figures A.3 to A.5.

A.1.3 Validation Checks on the Student Data

The results summary sheets were returned to the Open University head-quarters at Milton Keynes after marking by the students' tutors. The students' data were coded and transferred to computer disk. Results were only transferred where the tutor had marked the results as correct.

Once the results had been transferred to computer disk a number of simple checks were performed on the data. Cases with abnormally low or high measurements of L_{Aeq} , L_{A10} and L_{A90} , gaps in the data and results where the L_{A90} value was higher than the L_{A10} value or where the land use percentages did not add up to 100%, were identified. Where these faults occurred the computer values were checked against the original results summary sheets and where possible the faults were corrected. A number of the students had recorded the 100 spot readings on the results sheets but had not calculated the approximate L_{A10} and L_{A90} values. Where this occurred the L_{A10} and L_{A90} values were calculated and added to the computer data base thus maximising the data available for analysis.

Data of a dubious quality was deleted from the computer disk.

A.1.4 Sources of Error in the Student Data

The most important sources of error in the student data can be classified as:

1. errors due to deficiencies in the sound level meter,
2. errors due to the sampling method used to derive the noise levels and
3. human error.

Errors Due to Deficiencies in the Sound Level Meter

The sound level meters typically meet British Standard Specification for grade two meters but always the grade three specification. The specifications and meter performance requirements for these sound level meters are given in the British standard BS 5969:1981 (BSI 81).

Errors Due to the Sampling Method

The L_{A10} and L_{A90} values are derived from 100 spot readings of sound pressure level in dB(A) taken over a period of approximately five minutes. The L_{A10} value is given by taking the eleventh highest spot reading and the L_{A90} value is given by the eleventh lowest spot reading. This method for obtaining dB(A) values for L_{A10} and L_{A90} gives only a rough estimate of these values.

COMPULSORY NOISE EXPERIMENT

Results summary sheet

Enter L_{eq} value for
TV listening level
in dB(A)

Name Postcode

Date Time of start of measurement
(24-hour clock)

Meter Serial No.

Weather conditions

Tick all boxes that apply

Wind strength

- ☐ Calm (no wind)
☐ Slight air movement
☐ Light breeze
☐ Gentle breeze
☐ Moderate breeze

Recent rain

Or

Yes No

☐
☐

Spot readings record

Please write your 100 sound level meter measurements in the boxes below

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4	5	6	7	8	9	10
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
11	12	13	14	15	16	17	18	19	20
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
21	22	23	24	25	26	27	28	29	30
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
31	32	33	34	35	36	37	38	39	40
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
41	42	43	44	45	46	47	48	49	50
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
51	52	53	54	55	56	57	58	59	60
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
61	62	63	64	65	66	67	68	69	70
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
71	72	73	74	75	76	77	78	79	80
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
81	82	83	84	85	86	87	88	89	90
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
91	92	93	94	95	96	97	98	99	100

L_{90} in dB(A) deduced from these readings

L_{10} in dB(A) deduced from these readings

Figure A.3 Compulsory Noise Experiment results summary sheet (sheet 1)

Details concerning the spot readings

Time you began measurement (24-hour clock)

--	--	--	--

Total period of spot reading measurements to the nearest second mins secs

L_{eq} in dB(A) measured in the same location

Was this measurement of L_{eq} made at the same time as the spot readings?

Yes No
☐ ☐

Tick one box

Types of sources contributing to ambient level
Tick all boxes that apply

- | | | |
|--|---------------------------------------|--|
| <input type="checkbox"/> Road traffic | <input type="checkbox"/> Industry | <input type="checkbox"/> People and children |
| <input type="checkbox"/> Railway | <input type="checkbox"/> Construction | <input type="checkbox"/> Animals |
| <input type="checkbox"/> Aircraft | <input type="checkbox"/> Mowers | |
| <input type="checkbox"/> Other (specify) | | |

Source contributing most to ambient level

Type of adjacent road
Tick all boxes that apply

- | | | |
|---------------------------------------|---|--|
| <input type="checkbox"/> Motorway | <input type="checkbox"/> Dual carriageway | <input type="checkbox"/> Speed 30 m.p.h. |
| <input type="checkbox"/> A-road | <input type="checkbox"/> Bus route | <input type="checkbox"/> 40 m.p.h. |
| <input type="checkbox"/> B-road | <input type="checkbox"/> Cul-de-sac | <input type="checkbox"/> 50 m.p.h. |
| <input type="checkbox"/> Unclassified | <input type="checkbox"/> Flat road | <input type="checkbox"/> More than 50 m.p.h. |

Distance to nearest road (in metres)

Rating of ambient noise climate
Tick one box

How would you describe the noise level outside your home?

- ☐ Very noisy
☐ Noisy
☐ Quiet
☐ Very quiet

Figure A.4 Compulsory Noise Experiment results summary sheet (sheet 2)

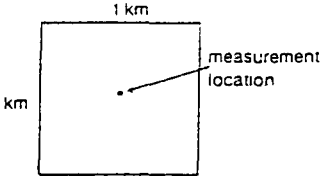
Traffic count (Heavy vehicles)	Number of goods vehicles (with more than four wheels), buses and coaches during 5 minutes	<input type="text"/>
	Description of traffic flow	
	<input type="checkbox"/> Free flowing	<input type="checkbox"/> Interrupted (stop/start)
		<input type="checkbox"/> Little or no traffic
Average peak noise level	Average peak noise level dBA	<input type="text"/>
	Number of measurements	<input type="text"/>
	Average peak noise level dBC	<input type="text"/>
	Number of measurements	<input type="text"/>
Classification of 1 km² area around your place of measurement	Estimates	
	<input type="text"/>	% Residential
	<input type="text"/>	% Industrial
	<input type="text"/>	% Commercial (shops and offices)
	<input type="text"/>	% Institutional (hospitals, schools, colleges, etc.)
	<input type="text"/>	% Open space
Types of roads in your area <i>Tick all boxes that apply</i>	<input type="checkbox"/> Motorway	
	<input type="checkbox"/> A-road	
	<input type="checkbox"/> B-road	
	<input type="checkbox"/> Unclassified	
Major noise sources outside area <i>Tick one only if appropriate</i>	<input type="checkbox"/> Airport	
	<input type="checkbox"/> Motorway	
	<input type="checkbox"/> Industry	
	<input type="checkbox"/> Construction	
	<input type="checkbox"/> Other (please specify)	
	Distance from measurement location in km	

Figure A.5 Compulsory Noise Experiment results summary sheet (sheet 3)

The L_{Aeq} value is derived by direct measurement also over a period of approximately 5 minutes.

These five minute samples may not be representative of the general noise environment prevailing within the area of measurement.

Human Errors

The main inaccuracies due to human error will result from:

1. mistakes in the operation and reading of the sound level meter,
2. misunderstanding the instructions,
3. mistakes in recording the data on the results sheets or in transforming the data on to computer disk.

These sources of error have been minimised by supplying the students with clear instructions and advice from course tutors where necessary and by double checking the results sheet data and checking the data on the computer for gross errors.

A.1.5 Summary of Student Data

This section briefly summarises the responses of the students given on the results summary sheet for the compulsory noise experiment that are particularly relevant to this thesis.

The student data are analysed in three parts:

1. all data,
2. all data for measurements taken on weekdays,
3. all data for measurements taken on weekdays between 6pm. and 10pm.

All Student Data

The types of noise sources contributing to the students measurements of ambient environmental noise are given in Table A.1. As expected road traffic is the most frequent contributory source of noise.

Details of the wind conditions at the time of measurement are given in Section 5.2.2.

The students were asked to take their measurements (when possible) on a weekday evenings. The majority of students were able to do this. Table A.2 shows the days of the week on which measurements were taken. It can be seen that 82.7% of the students took their measurements between Monday and Friday inclusive.

Measurements Taken on Weekdays

Table A.3 Shows the time of day when the weekday measurements were taken. The day has been split into characteristic noise periods.

Table A.1 Types of noise sources contributing to the ambient noise levels

Noise source	Number of sites affected	Percentage of sites affected
Road traffic	245	58.9
People & children	45	10.8
Wind/trees	21	5.0
Industry	19	4.6
Birds	17	4.1
Aircraft	16	3.8
Mowers	15	3.6
Animals	9	2.2
Construction	4	1.0
Pump	2	0.4
Sea	2	0.4
Harvester	1	0.2
Railway	1	0.2
Milking machine	1	0.2
No response	18	4.3
Total	416	100

Table A.2 Day of the week when measurements were taken by the students

Day of week	Number of measurements	Percentage of measurements
Sunday	39	9.4
Monday	72	17.3
Tuesday	80	19.2
Wednesday	60	14.4
Thursday	63	15.1
Friday	69	16.6
Saturday	31	7.5
No response	2	0.5
Total	416	100

Table A.3 Time of commencing weekday measurements

Time period	Number of measurements	Percentage of measurements
12pm. - 8am.	0	0
8am. - 10am.	3	0.9
10am. - 4pm.	29	8.4
4pm. - 6pm.	50	14.5
6pm. - 10pm.	255	74.1
10pm. - 12pm.	7	2.0
No response	0	0
Total	344	100

It can be seen that the majority of students have taken their measurements on weekdays between 6pm. and 10pm. (57.5%). Only 28% of students took measurements between 10am. and 4pm. which can be directly compared with the data from the three case study areas.

A.1.6 Noise levels (6pm. - 10pm.)

Tables A.4 to A.7 give the wind corrected average L_{Aeq} , L_{A10} , L_{A90} and ($L_{A10} - L_{A90}$) weekday measurements taken between 6pm. and 10pm. for each of the area-types in the noise prediction matrix, and for the data as a whole. The standard deviation of the data and number of measurements are also given. Noise measurements that are suspect and those taken on the bank holiday monday have been excluded from the analysis. Forty-eight measurements were taken on Mondays, fifty-nine on Tuesdays, forty-five on Wednesdays, forty-four on Thursdays and forty-three on Fridays.

The average time taken by the students to take the 100 spot readings of sound power level is approximately six minutes. 74.5% of the students took the L_{Aeq} measurement at the same time as taking the 100 spot readings.

44.8% of the students took measurements when there had been recent rain, 45.6% took measurements when there had been no recent rain and 9.6% of the students did not respond to this question. The weather conditions at the time of measurement were defined as dry by 73.6% of the students, 11.8% of the students took measurements when conditions were not dry and 14.6% of the students did not respond to this question.

The types of sources contributing to the ambient noise level are given in Table A.8. Again road traffic is the most frequent source of noise contributing to the ambient noise levels.

Details of the estimated land use percentages for the 1 km² square around these measurement sites are given in Section B.4.3.

Table A.4 Wind corrected L_{Aeq} (weekdays 6 pm. - 10 pm.)

Land use	Traffic density (Veh. km/hr/km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space		52.0 (-) N = 1	48.9 (5.6) N = 18	46.5 (9.3) N = 17	58.0 (-) N = 1
Residential		50.0 (9.7) N = 16	51.6 (7.9) N = 64	50.7 (9.3) N = 71	51.0 (5.5) N = 6
Commercial					
Industrial					
Residential/ Commercial		50.0 (5.4) N = 4	49.6 (3.5) N = 4	52.5 (6.9) N = 6	56.9 (9.8) N = 2
Residential/ Industrial		62.0 (17.0) N = 2	55.9 (7.9) N = 5	57.0 (10.9) N = 15	52.3 (-) N = 1
Commercial/ Industrial					
Residential/ Commercial/ Industrial				68.9 (-) N = 1	

Mean L_{Aeq} for all measurements taken on weekdays between 6pm. and 10pm.
 = 51.3 dB(A)
 Standard deviation of measurements = 8.8 dB(A)
 Number of measurements (N) = 234

Table A.5 Wind corrected L_{A10} (weekdays 6 pm. - 10pm.)

Land use	Traffic density (Veh. km/hr/km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space		51.0 (-) N = 1	52.6 (7.5) N = 19	49.5 (9.3) N = 17	61.0 (-) N = 1
Residential		56.1 (8.3) N = 16	55.7 (8.1) N = 65	53.3 (9.7) N = 73	58.1 (10.1) N = 7
Commercial					
Industrial					
Residential/ Commercial		55.4 (8.0) N = 4	53.9 (1.9) N = 4	57.1 (7.7) N = 6	59.5 (10.5) N = 2
Residential/ Industrial		67.0 (18.3) N = 2	57.6 (10.0) N = 5	61.7 (11.4) N = 15	59.7 (-) N = 1
Commercial/ Industrial					
Residential/ Commercial/ Industrial				64.9 (-) N = 1	

Mean L_{A10} for all measurements taken on weekdays between 6pm. and 10pm.

= 54.9 dB(A)

Standard deviation of measurements = 9.3 dB(A)

Number of measurements (N) = 239

Table A.6 Wind corrected L_{A90} (weekdays 6 pm. - 10 pm.)

Land use	Traffic density (Veh. km/hr/km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space		40.0 (-) N = 1	39.5 (6.5) N = 19	39.0 (7.4) N = 17	51.0 (-) N = 1
Residential		42.6 (6.7) N = 16	41.6 (7.0) N = 65	41.4 (6.9) N = 73	44.3 (5.6) N = 7
Commercial					
Industrial					
Residential/ Commercial		40.4 (4.2) N = 4	45.5 (5.0) N = 4	41.5 (5.7) N = 6	49.3 (13.2) N = 2
Residential/ Industrial		50.8 (18.2) N = 2	43.9 (7.2) N = 5	46.0 (10.2) N = 15	44.9 (-) N = 1
Commercial/ Industrial					
Residential/ Commercial/ Industrial				59.7 (-) N = 1	

Mean L_{A90} for all measurements taken on weekdays between 6pm. and 10pm.

= 42.0 dB(A)

Standard deviation of measurements = 7.4 dB(A)

Number of measurements (N) = 239

Table A.7 Wind corrected ($L_{A10} - L_{A90}$) (weekdays 6 pm. - 10 pm.)

Land use	Traffic density (Veh. km/hr/km ²)				
	0-500	501-1000	1001-2000	2001-4000	4001-8000
Open space		11.0 (-) N = 1	13.1 (6.3) N = 19	10.5 (5.0) N = 17	10.0 (-) N = 1
Residential		13.4 (5.0) N = 7	14.1 (6.4) N = 65	11.9 (6.2) N = 73	13.8 (10.3) N = 7
Commercial					
Industrial					
Residential/ Commercial		15.0 (5.4) N = 4	8.5 (3.2) N = 4	15.6 (7.4) N = 6	10.1 (2.7) N = 2
Residential/ Industrial		16.1 (0.2) N = 2	13.7 (8.9) N = 5	15.7 (6.3) N = 15	14.8 (-) N = 1
Commercial/ Industrial					
Residential/ Commercial/ Industrial				5.1 (-) N = 1	

Mean $L_{A10} - L_{A90}$ for all measurements taken on weekdays between 6pm.
and 10pm. = 13.0 dB(A)

Standard deviation of measurements = 6.3 dB(A)

Number of measurements (N) = 239

Table A.8 Types of noise sources contributing to ambient noise levels

Source	Number of sites	Percentage of sites
Road traffic	138	57.7
People and children	29	12.1
Aircraft	14	5.9
Wind/trees	11	4.6
Birds	10	4.2
Animals	9	3.8
Mowers	8	3.3
Construction	2	0.8
Harvester	1	0.4
Pump	1	0.4
Sea	1	0.4
No response	15	6.3
Total	239	100

The number of student measurements of L_{Aeq} , L_{A10} , L_{A90} and $L_{A10} - L_{90}$ in each of the regions is shown in Figures A.6 and A.7.

A.2 Comparison between the Three Case Study Area and the Student Noise Data

A summary of the main differences between the three case study area and student noise data is given in Table A.9.

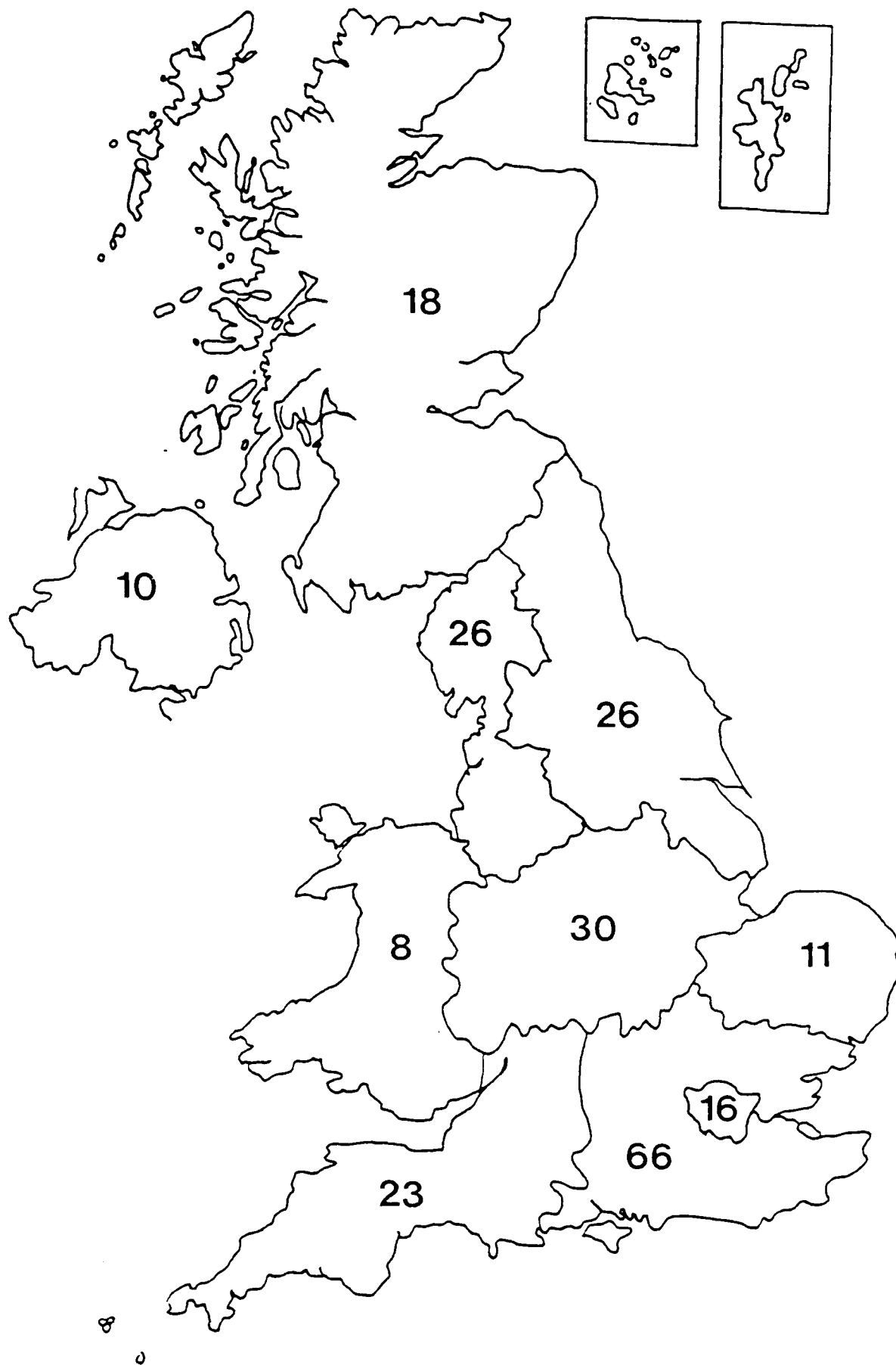


Figure A.6 The number of student measures of L_{Aeq} (6pm. to 10pm.) in each of the regions

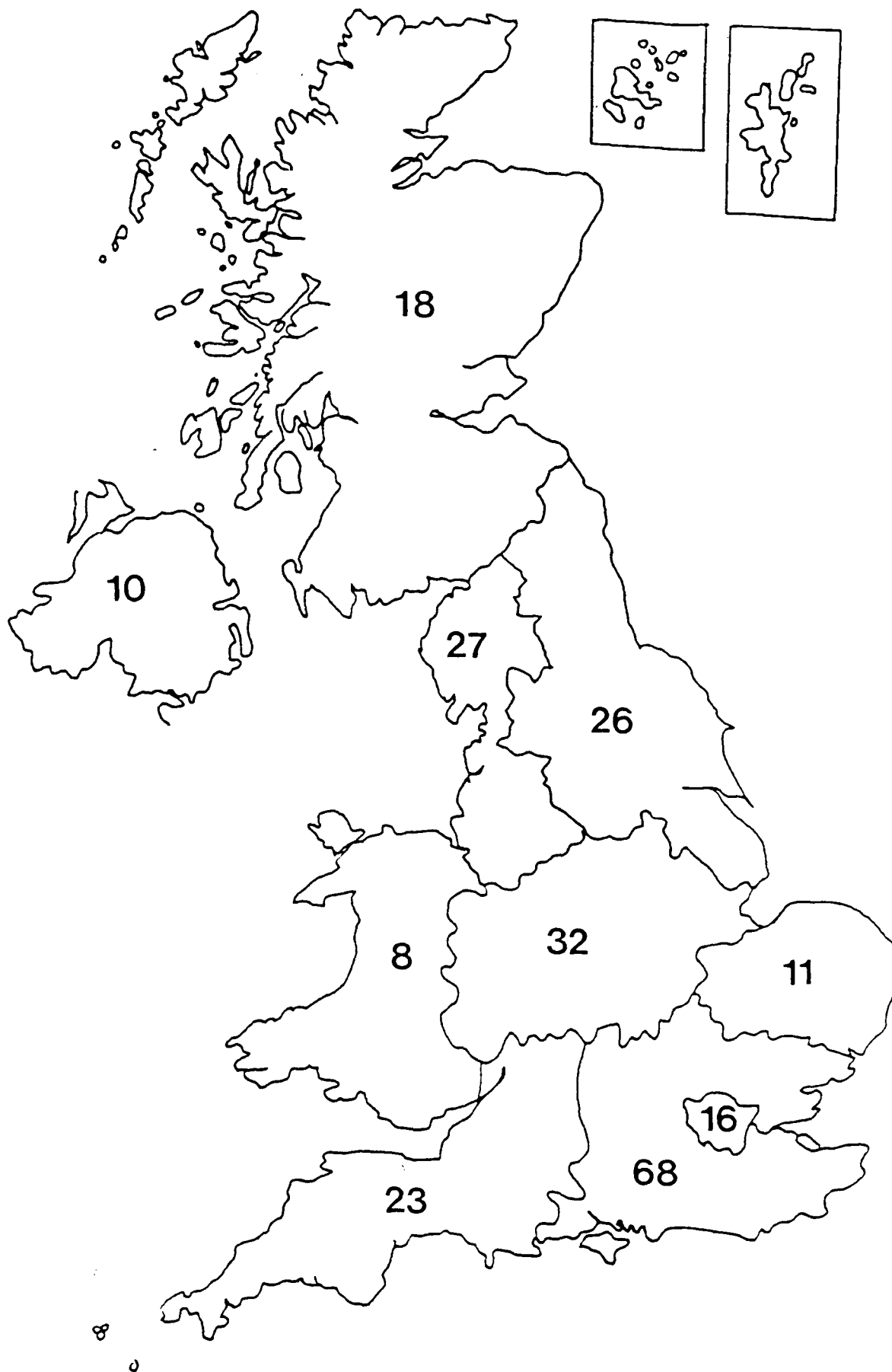


Figure A.7 The number of student measures of L_{A10} and L_{A90} (6pm. to 10pm.) in each of the regions

Table A.9 The Main Differences between the Three Case Study Area and Student of Noise Data

Characteristic	Three case study area data	Student data
Selected time period	10am. to 4pm.	6pm. to 10pm.
Number of measurements per 1 km ² square	25	1
Position of measurements	Nodes of a superimposed grid	Centre
Method for deriving L _{A10} & L _{A90} values	Direct measurement	100 spot readings
Derivation of land use classification	Using land use data	Using subjective estimates by students
Derivation of traffic density classification	Traffic flow & road length data	Types of road in the 1 km ² square
Surveyor	Post graduate student	Under graduate student
Sound level meter grade	Grade 1	Industrial grade 3
Regional distribution of	Three case study areas	Throughout the United Kingdom

Appendix B

Technical considerations on demographic characteristics

B.1 Processing of the London Borough of Bexley land use data

Figure B.1 shows the format of the Greater London Council's land use survey data. A key to the various land use categories shown in Figure B.1 is given below:

- CD Local authority depots
- CF Food and non-food storage, furniture repositories and any other covered storage not included below
- CM Wholesale markets
- CP Storage of petrol, oil and other liquid chemicals
- CS Timber yards and open storage
- CW Commercial warehouses
- CY Builders' yards, depots (milk depots code CF)
- EF Further education, private or local authority
- EP Educational playing fields (whether adjacent to or separate from schools)
- ES All schools except those used mainly for further education (i.e. including nursery, primary, secondary, grammar, comprehensive, special, whether private, independent or local authority maintained)
- EU Universities
- GA Allotments (except in public parks or on railway land)
- GC Cemeteries and crematoria
- GF Farming land (including farmhouses and commercial woodlands)

24 MAR 1984

GREATER LONDON LAND USE SURVEY 19

PAGE 053

BOROUGH NO. 18 - BEXLEY

MAP QUADRANT 4977 NW

SITE AREA AND FLOOR SPACE BY USE - TABLE 1

MAIN USE		USE SUB-DIVISIONS										MAIN USE TOTALS	
C	COMMERCE	CD	CF 3.725 1.97	CM	CP	CS	CW	CY				COMMERCE 3.725 1.97	
E	EDUCATION	EF	EP 6.300	ES 5.273	EU							EDUCATION 11.650	
G	OPEN AREAS	GA 2.155	GC 8.355	GF	GN	GP 10.360	GR 0.495				OPEN AREAS 21.065		
H	HEALTH	HR	HV 3.003								HEALTH 3.003		
I	INDUSTRY	IN 0.035 0.14									INDUSTRY 0.035 0.14		
M	MINERAL WORKINGS	MB	MC	MS							MINERAL WORKINGS		
O	OFFICES	OC	OG	OI	OP 3.025 0.08						OFFICES 3.025 0.08		
P	PUBLIC BUILDINGS	PA	PC 0.135	PE	PF	PG	PM	PR 3.230	PS			PUBLIC BUILDINGS 3.365	
R	RESIDENTIAL	RB	RC	RH	RM	RP 49.314	RW				RESIDENTIAL 49.314		
S	SHOPS	SB	SD	SF 3.081 0.62	SG 0.013 0.37	SN 0.060 0.32	SO 0.005	SP 0.296 0.96	SV 0.045 0.06			SHOPS 3.500 2.03	
T	TRANSPORT	TA	TB	TC 0.140	TD 0.372	TE 0.013	TG	TH 10.940	TL 0.155	TP	TR	TT	TRANSPORT 11.620
U	UTILITIES	UE 0.165	UG	UM 0.005	UR	US	UT	UW				UTILITIES 0.170	
V	VACANT LAND	VC	VD 0.105	VE	VF 4.290	VG	VH 0.013 0.04	VI	VJ			VACANT LAND 4.408 0.04	
W	WATER	WN	WO	WP								WATER	
SITE AREA IS IN HECTARES FLOOR SPACE IS IN TENS OF SQUARE METRES												GRAND TOTAL	99.880

SITE AREA IS IN HECTARES
FLOOR SPACE IS IN THOUSANDS OF SQUARE METRES

345

Figure B.1 Format of 1971 Greater London land use survey data

- GN Nurseries, commercial glasshouses, orchards, market gardens and small-holdings
- GP Open space with full or limited public access (including allotments in such open spaces, public golf courses and bowling greens)
- GR Private open spaces (including private golf courses, playing fields, tennis courts, bowling greens, etc.), and playgrounds independent of public parks and housing estates
- HR Hospitals, nursing homes, convalescent homes, sanatoria
- HV Clinics, health centers, occupational centers, surgeries and consulting rooms, day nurseries
- IN All industry, including abattoirs
- MB Brickworks
- MC Chalk and lime
- MS Sand and gravel workings
- OC Central government offices, including local Ministry offices but excluding Post Offices
- OG Banks, insurance companies, estate agents, friendly societies, offices of firms engaged in trade, transport, distribution, manufacturing, servicing, publishing, advertising, building and civil engineering, agriculture, entertainment, sport (other than betting shops), professional offices (e.g., solicitors, accountants, architects, etc.)
- OL Local government offices
- OP Offices of statutory boards, corporations, societies, institutions, unions, political parties, livery companies, research institutes
- PA Concert halls, cinemas, theatres
- PC Clubs (excluding sports clubs)
- PE Embassies, legations and consulates
- PF Land and buildings used by the armed forces
- PG Museums, art galleries, libraries, broadcasting and television studios, assembly halls and other places of public (non-active) entertainment
- PM Public buildings not included elsewhere
- PR Churches and other places of worship including halls and Sunday Schools associated with them
- PS Swimming pools, skating rinks, dance halls and dancing schools, sports stadia, dog tracks, indoor tennis, squash, etc., courts, covered rifle ranges, billiard saloons and other places of public (active) entertainment
- RB Nurses and students hostels, school boarding accommodation

- RC Caravan sites
- RH Hotels with accommodation
- RM Other boarding accommodation
- RP Private residential premises including residential quarters in separate buildings
- RW Old people's and children's homes
- SB Betting shops
- SD Department stores, chain stores
- SF Food shops
- SG Shops and service establishments not included elsewhere
- SN Non-food shops
- SO Sales from open land (including motor vehicles)
- SP Public houses including living accommodation
- SV Vehicle showrooms
- TA Airports including heliports
- TB Bus stations
- TC Private car or lorry parks (when separate from other uses)
- TD Road haulage depots, taxi or private hire garages, bus garages, vehicle repair garages
- TF Petrol filling stations
- TG Public garages
- TH Roads
- TL Lock-up garages
- TP Open car parks (public)
- TR Railway land (including railway allotments)
- TT Air terminals
- UE Electric power stations, transformers, sub-stations, etc.
- UG Gas works
- UM Other public utilities (including lavatories)
- UR Refuse tips and destructors
- US Sewage works and installations
- UT Telephone exchanges, General Post Office sorting offices
- UW Waterworks and pumping stations

Table B.1 Grouping of the GLC land use data into the land use predictor variables

Land use predictor variable	GLC land use categories
Open space	EP, GA, GC, GF, GN, GP, GR, VD, VI, VL, VO, VS, VU, VW, WN, WT and WU.
Residential	HR, HV, RB, RC, RH, RM, RP and RW.
Commercial	EF, ES, EU, OC, OG, OL, OP, PA, PC, PE, PF, PG, PM, PR, PS, SB, SD, SF, SG, SN, SO, SP, SV, TA, TB, TC, TD, TF, TL, TP, TR, TT, UG, UM, and UT.
Industry	CD, CF, CM, CP, CS, CW, CY, IN, MB, MC, MS, TG, UE, UR, US, UW and VC.

- VC Buildings under construction
- VD Derelict buildings
- VI Vacant but not derelict industrial premises
- VL Vacant land (including hoarding sites)
- VO Vacant but not derelict office premises
- VS Vacant but not derelict shop premises
- VU Unoccupied premises (other than houses or flats)
- VW Vacant but not derelict warehouse premises
- WN Non-tidal waters (navigable), including canals
- WT Tidal waters
- WU Non-tidal water (un-navigable)

The detailed nature of the land use survey data provided the opportunity to group the land use categories according to the criteria described in Section 4.4.2.

The Greater London Council's land use categories were grouped into the four land use predictor variables, used in this thesis to characterise each 1 km² square, as shown in Table B.1.

The area of land taken up by roads (TH) is split proportionately between the land use categories: open space, residential, commercial and industrial.

An alphabetical index to the various GLC land uses and their corresponding survey codes are given in the GLC research report No. 8, 'The land use survey 1966' (GLC 72).

Table B.2 Derivation of student vehicle density indicator

Motorway	A-road	B-road	C-road	Vehicle density code
✓				2
✓	✓			2
✓		✓		2
✓			✓	2
✓	✓	✓		1
✓	✓		✓	1
✓		✓	✓	1
✓	✓	✓	✓	1
	✓			4
	✓	✓		3
	✓		✓	2
	✓	✓	✓	2
		✓		4
		✓	✓	3
			✓	3
				5

B.2 Derivation of Student Vehicle Density Variable

The Students were asked to give information on the types of road found within the 1 km² square area around their measurement location. The roads were classified either as motorway, A-road, B-road or unclassified. Data on the lengths of these roads in the 1 km² square were not provided by the students.

The types of roads in the 1 km² square are used to derive a rough estimate of the vehicle density within the 1 km² square. Five vehicle density indicator categories were chosen to roughly correspond to the vehicle density categories defined in the theoretical prediction matrix. Each of the vehicle density indicator categories is assigned a code number such that:

Code 5 \cong 4001 - 8000

Code 4 \cong 2001 - 4000

Code 3 \cong 1001 - 2000

Code 2 \cong 501 - 1000

Code 1 \cong 0 - 500

Table B.2 shows the various combinations of road types and their corresponding vehicle density code.

The classification system is based upon a hypothesised relationship between the road types within the 1 km² square and its vehicle density (veh.km/hr/km²).

The three case study area data are used to test the correlation between the two

Table B.3 Correlations between vehicle and road density variables

Variable	Vehicle density	Vehicle density (student)	Network density (Pocock)
Vehicle density (3 case study areas)	1.000 (43) P = 0.000	-0.6295 (43) P = 0.000	-0.1007 (43) P = 0.521
Vehicle density (student)	-0.6295 (43) P = 0.000	1.000 (43) P = 0.000	-0.0137 (43) P = 0.932
Network density (Pocock)	-0.1007 (43) P = 0.521	-0.0137 (43) P = 0.932	1.000 (43) P = 0.000

(Pearson correlation coefficient/(cases)/two-tailed significance)

(differently derived) vehicle density variables. The Pearson correlation coefficient and the two-tailed significance for this relationship is given in Table B.3. The correlation between these vehicle density variables and Pocock's road network density variable is also given in Table B.3.

It can be seen that there is an inverse relationship between the two methods for deriving an estimate of the vehicle density. This result is discussed further on Page 166.

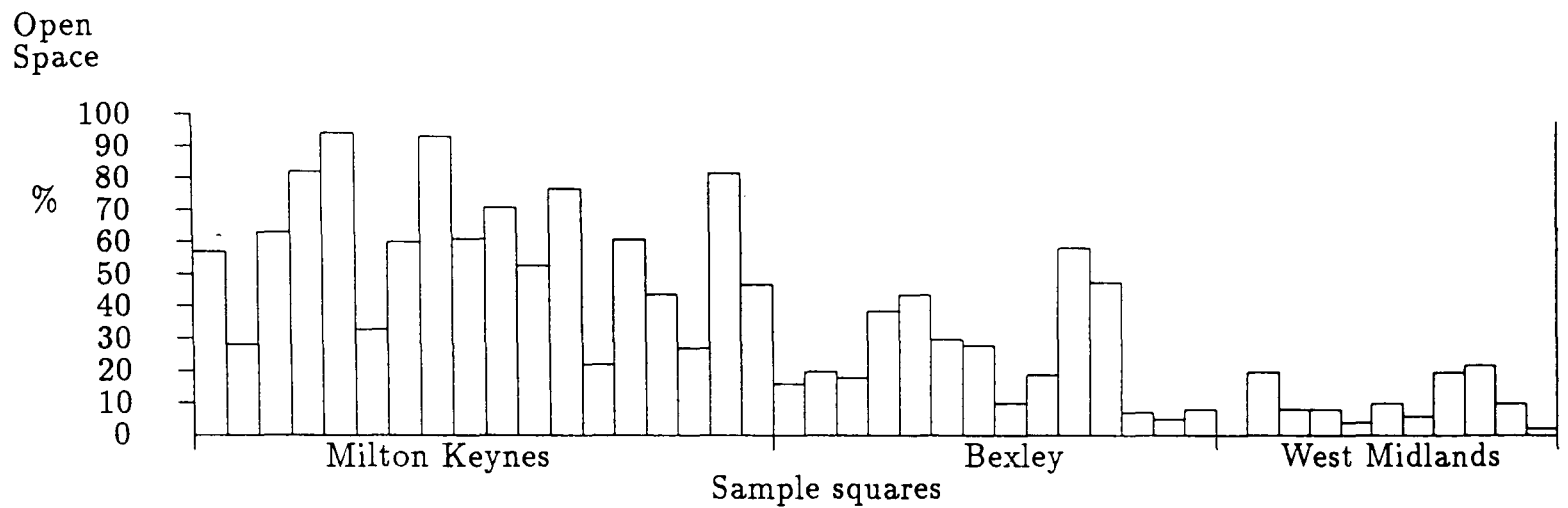


Figure B.2 Percentage of open space in each of sample squares.

B.3 Types and Mix of Area-Type Characteristics within the sample squares

B.3.1 Three Case-Study Area Data

A broad selection of land use mixture and vehicle densities are surveyed from each case study area.

Figures B.2 to B.6 show the percentages of land use and vehicle density levels in each of the 1 km² square sampled.

The most apparent differences between the groups of 1 km² squares from each of the case study areas are the different percentages of open space and residential land use in each group of 1 km² square.

The average of the percentages of open space in each of the case study areas are given in Table B.4.

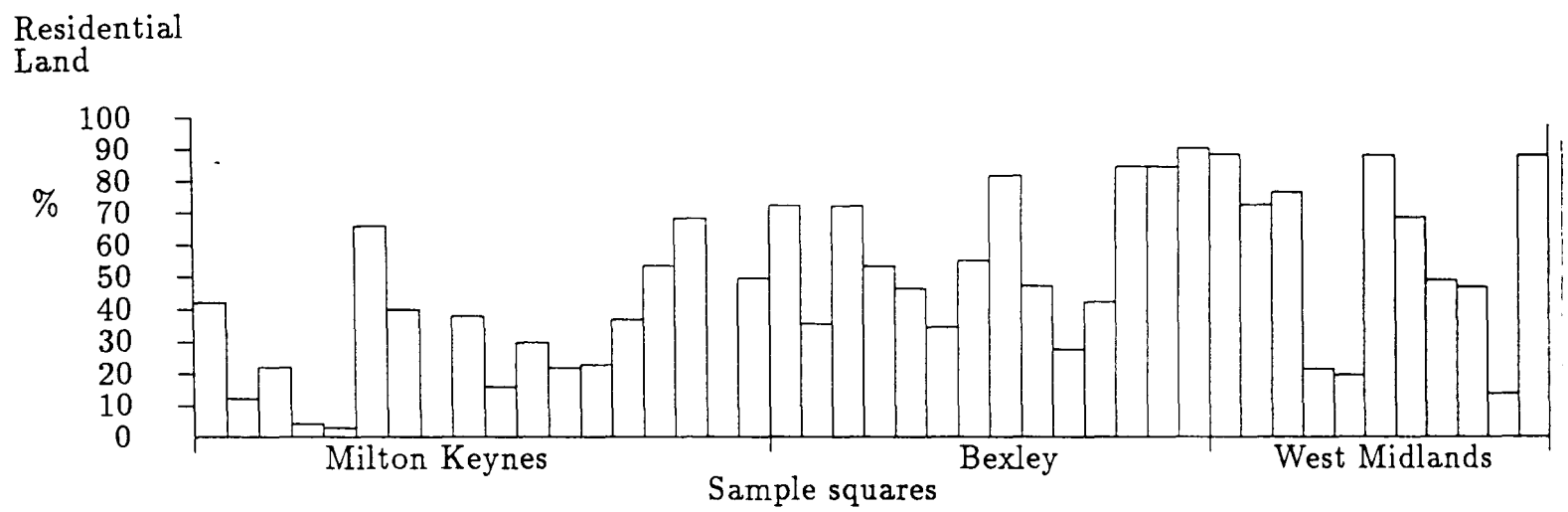


Figure B.3 Percentage of residential land use in each of the sample squares.

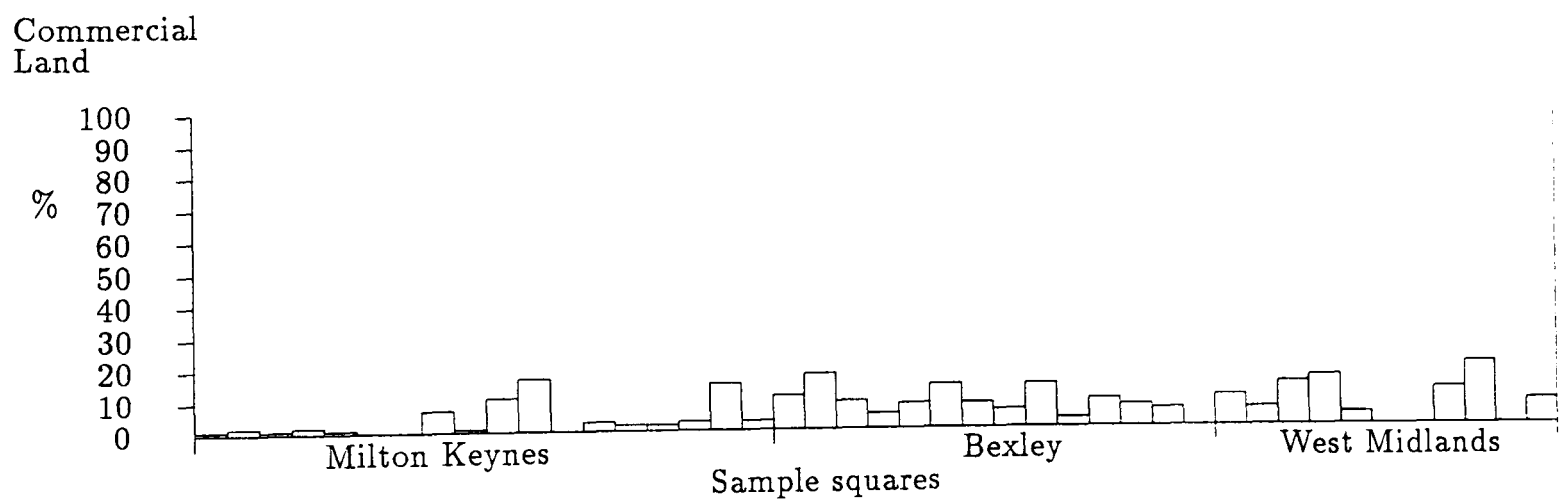


Figure B.4 Percentage of commercial land use in each of the sample squares.

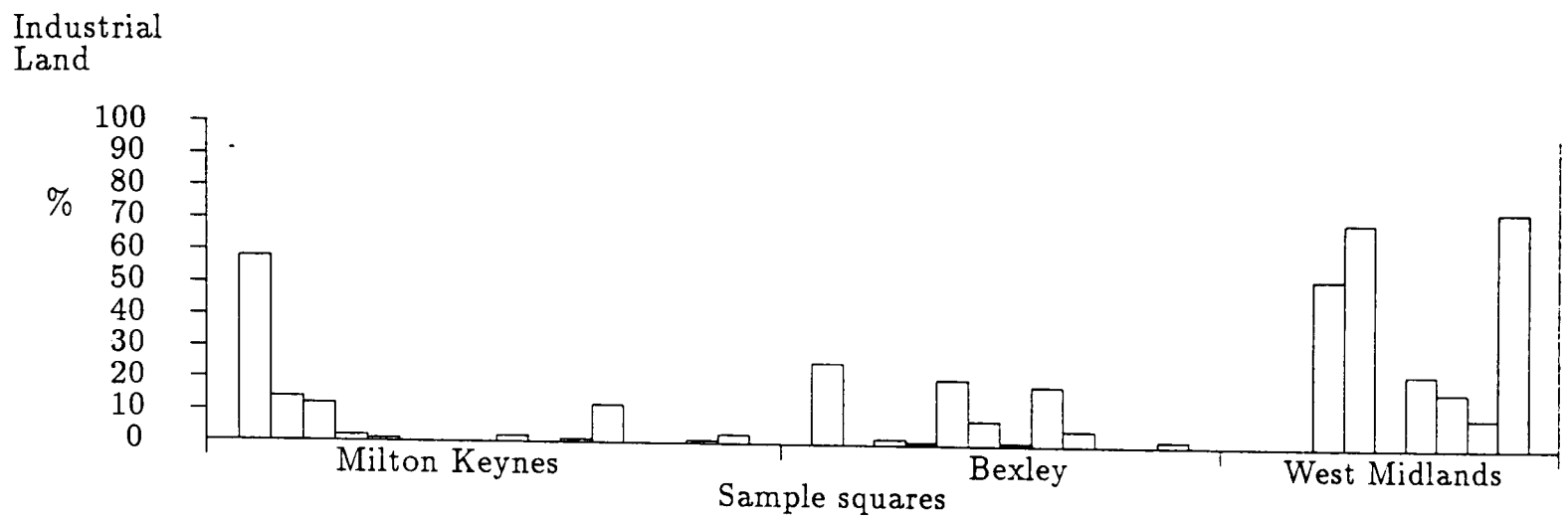


Figure B.5 Percentage of industrial land use in each of the sample squares.

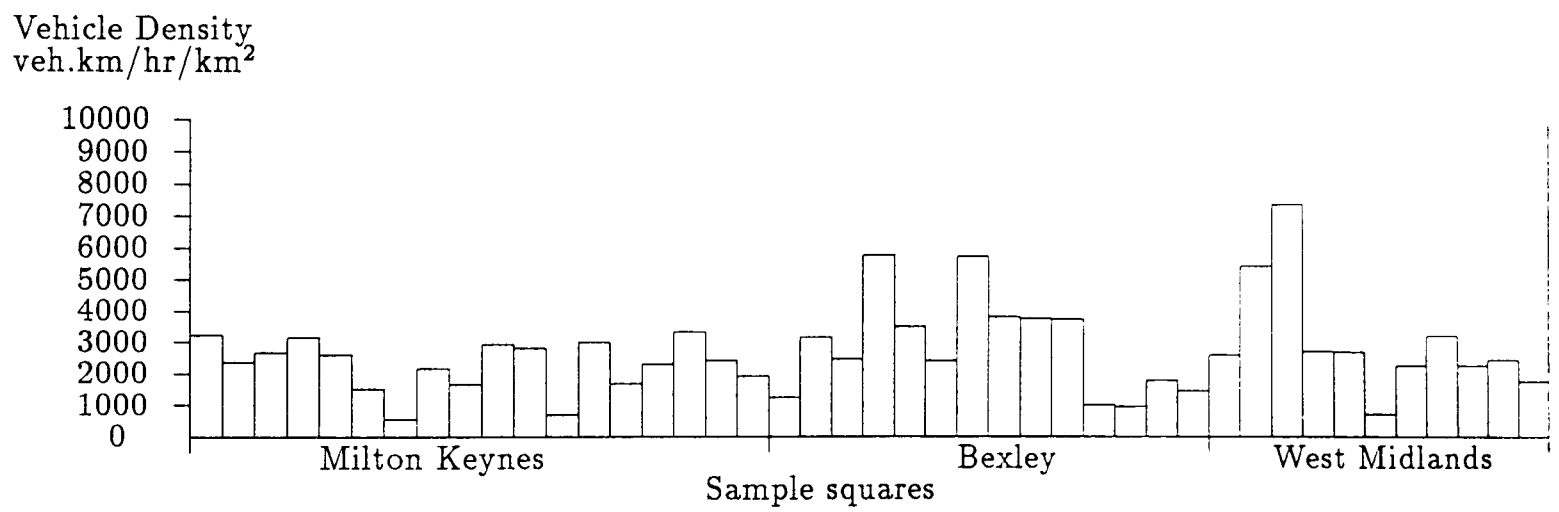


Figure B.6 Vehicle densities in each of the sample squares

Table B.4 Average percentage of open space in the sample squares from each of the case study areas.

	Milton Keynes	Bexley	West Midlands
Average % open space	59.7%	26.8%	9.8%

Table B.5 Average percentage residential land use in the sample squares from each of the case study areas.

	Milton Keynes	Bexley	West Midlands
Average % Residential land use per km ²	29.3%	57.5%	73.8%

As the percentage of open space decreases across the case study areas so the percentages of residential land use increases. The average percentages of these land uses in the 1 km² squares in each of the case study areas are given in Table B.5.

The percentage of commercial land use remains fairly constant across all of the 1 km² squares sampled. The range of commercial land use is 0 to 20%, two thirds of the 1 km² squares having less than 10% commercial land use.

Industrial land use and vehicle density are more variable with a range from 0 - 76% and 560 - 7472 veh. km/hr/km² respectively.

The differences in the type and mix of land use within each of the case study areas is not due to different sampling strategies in each region.

B.4 Correlations between demographic variables

B.4.1 Correlations using data from all 3 case study areas

The Pearson correlation coefficients for the relationships between the demographic variables across all three case study areas are given in Table B.6.

As expected there is a high negative correlation between residential land use and open space.

There are smaller negative correlations between industrial land use and the two land uses residential and open space

In Section 3.2.4 it is hypothesised that there would be a negative correlation between open space and vehicle density due to open space being a non traffic generating land use. As a result of this hypothesis open space was not included in the land use mix categories used to define the land use axis of the prediction matrix.

Table B.6 Correlations between the demographic characteristics of all sample squares

Land Use	Open space	Residential land	Commercial land	Industrial land	Vehicle density
Open space	1.0000 (43) P=0.000	-0.7303 (43) P=0.000	-0.2184 (43) P=0.159	-0.3050 (43) P=0.047	-0.0919 (43) P=0.558
Residential land	-0.7303 (43) P=0.000	1.0000 (43) P=0.000	-0.0056 (43) P=0.971	-0.3983 (43) P=0.008	0.0099 (43) P=0.950
Commercial land	-0.2184 (43) P=0.159	-0.0056 (43) P=0.971	1.0000 (43) P=0.000	0.0182 (43) P=0.908	0.2721 (43) P=0.078
Industrial land	-0.3050 (43) P=0.047	-0.3983 (43) P=0.008	0.0182 (43) P=0.908	1.0000 (43) P=0.000	0.0346 (43) P=0.825
Vehicle density	-0.0919 (43) P=0.558	0.0099 (43) P=0.950	0.2721 (43) P=0.078	0.0346 (43) P=0.825	1.0000 (43) P=0.000

(Pearson correlation coefficient/ (No. of cases) / 2-tailed significance)

Table B.7 Correlations between the demographic characteristics of the Milton Keynes sample squares

Land Use	Open space	Residential land	Commercial land	Industrial land	Vehicle density
Open space	1.0000 (18) P=0.000	-0.7765 (18) P=0.000	0.2016 (18) P=0.423	-0.3162 (18) P=0.201	-0.0292 (18) P=0.909
Residential land	-0.7765 (18) P=0.000	1.0000 (18) P=0.000	-0.3422 (18) P=0.165	-0.3106 (18) P=0.210	-0.1527 (18) P=0.545
Commercial land	0.2016 (18) P=0.423	-0.3422 (18) P=0.165	1.0000 (18) P=0.000	-0.1291 (18) P=0.610	0.3317 (18) P=0.179
Industrial land	-0.3162 (18) P=0.201	-0.3106 (18) P=0.210	-0.1291 (18) P=0.610	1.0000 (18) P=0.000	0.1595 (18) P=0.527
Vehicle density	-0.0292 (18) P=0.909	-0.1527 (18) P=0.545	0.3317 (18) P=0.179	0.1595 (18) P=0.527	1.0000 (18) P=0.000

(Pearson correlation coefficient/ (No. of cases) / 2-tailed significance)

It can be seen that from Table B.6 the correlation is very poor. This indicates that the omission of open space from the land use mix categories may be a source of error in the prediction model.

B.4.2 Regional differences in correlation coefficients

Tables B.7 to B.9 give the Pearson correlation coefficients for the relationships between the demographic variables in each of the case study areas.

Open space and residential land use are highly negatively correlated in both Milton Keynes and Bexley. However, there is little correlation in the West Midlands due to the small range of open space percentages in that region (0 - 22%) and due to the influence of industrial land use.

There is a high negative correlation between industrial land use and residential land use in the West Midlands.

Table B.8 Correlations between the demographic characteristics of the Bexley sample squares

Land Use	Open space	Residential land	Commercial land	Industrial land	Vehicle density
Open space	1.0000 (13) P=0.000	-0.7851 (13) P=0.001	-0.2711 (13) P=0.370	-0.0401 (13) P=0.896	0.3377 (13) P=0.259
Residential land	-0.7851 (13) P=0.001	1.0000 (13) P=0.000	-0.3301 (13) P=0.271	-0.5772 (13) P=0.039	-0.3545 (13) P=0.235
Commercial land	-0.2711 (13) P=0.370	-0.3301 (13) P=0.271	1.0000 (13) P=0.000	0.8004 (13) P=0.001	-0.1390 (13) P=0.651
Industrial land	-0.0401 (13) P=0.896	-0.5772 (13) P=0.039	0.8004 (13) P=0.001	1.0000 (13) P=0.000	0.2073 (13) P=0.497
Vehicle density	0.3377 (13) P=0.259	-0.3545 (13) P=0.235	-0.1390 (13) P=0.651	0.2073 (13) P=0.497	1.0000 (13) P=0.000

(Pearson correlation coefficient/ (No. of cases) / 2-tailed significance)

Table B.9 Correlations between the demographic characteristics of the West Midlands sample squares

Land Use	Open space	Residential land	Commercial land	Industrial land	Vehicle density
Open space	1.0000 (12) P=0.000	-0.1973 (12) P=0.539	0.3375 (12) P=0.283	-0.1260 (12) P=0.696	0.2181 (12) P=0.496
Residential land	-0.1973 (12) P=0.539	1.0000 (12) P=0.000	-0.1694 (12) P=0.599	-0.9229 (12) P=0.000	-0.0062 (12) P=0.985
Commercial land	0.3375 (12) P=0.283	-0.1694 (12) P=0.599	1.0000 (12) P=0.000	-0.1492 (12) P=0.643	0.3731 (12) P=0.232
Industrial land	-0.1260 (12) P=0.696	-0.9229 (12) P=0.000	-0.1492 (12) P=0.643	1.0000 (12) P=0.000	-0.1359 (12) P=0.674
Vehicle density	0.2181 (12) P=0.496	-0.0062 (12) P=0.985	0.3731 (12) P=0.232	-0.1359 (12) P=0.674	1.0000 (12) P=0.000

(Pearson correlation coefficient/ (No. of cases) / 2-tailed significance)

B.4.3 Student Land Use Data

The students were asked to estimate the percentage of open space, residential, commercial (shops, and office works), institutional (hospitals, schools, colleges, etc.) and industrial land use within a 1 km² square area around their measurement location. Figures B.7 to B.11 show the frequency distribution of these land use estimates. Figure B.12 shows the frequency distribution for the commercial and institutional land use percentage estimates for the areas surveyed on working weekdays between 6pm. and 10pm.

The data show a marked tendency for the students to estimate the percentages in units of five or ten percent and demonstrates one of the draw backs of using subjective assessments of land use percentages.

As expected there is a high percentage of residential land use in the areas surveyed by the students as, by definition, the open university students tend to live in residential areas which normally coincides with their noise measurement locations.

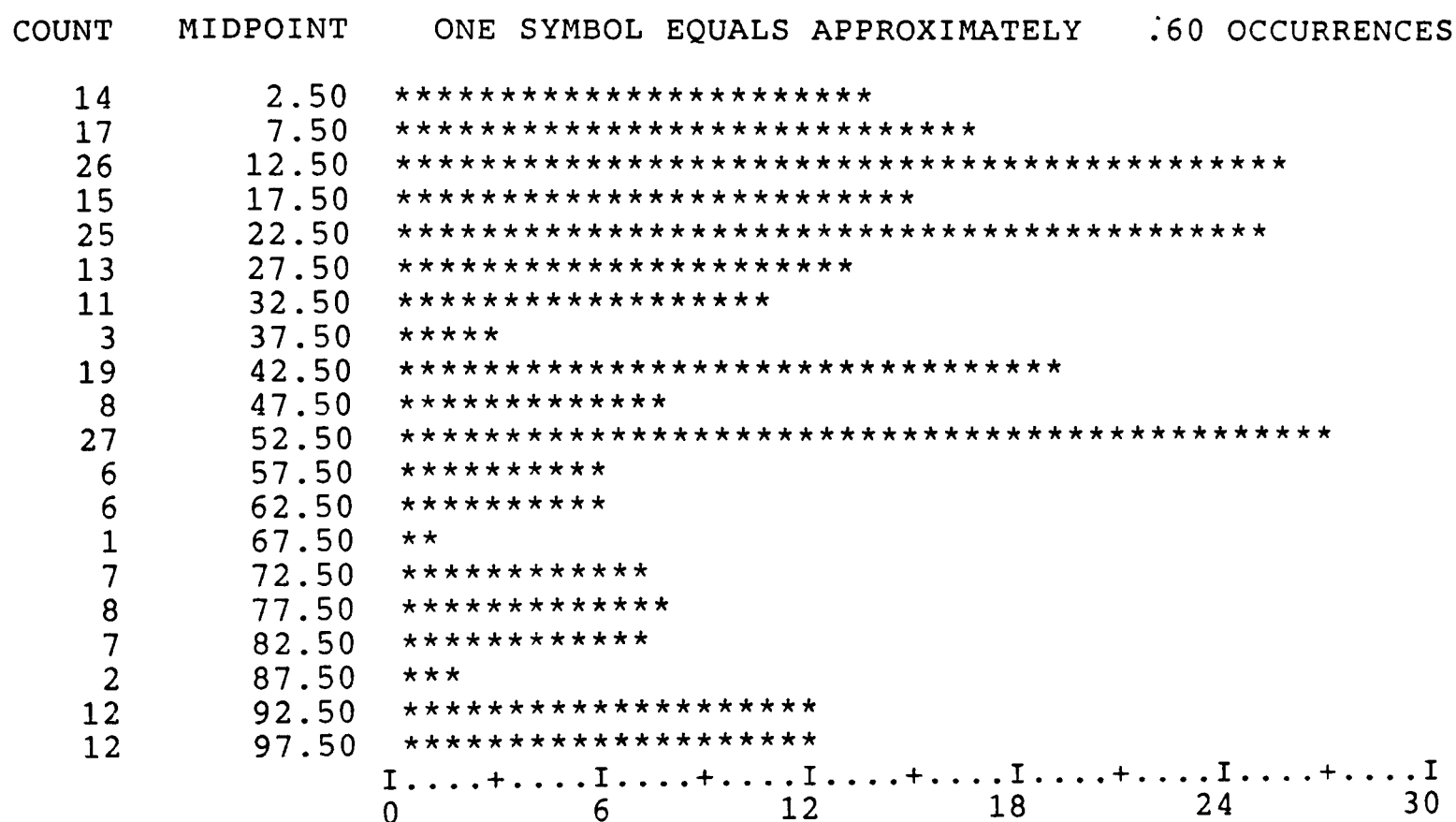


Figure B.7 Frequency distribution of the percentage open space estimated by the students

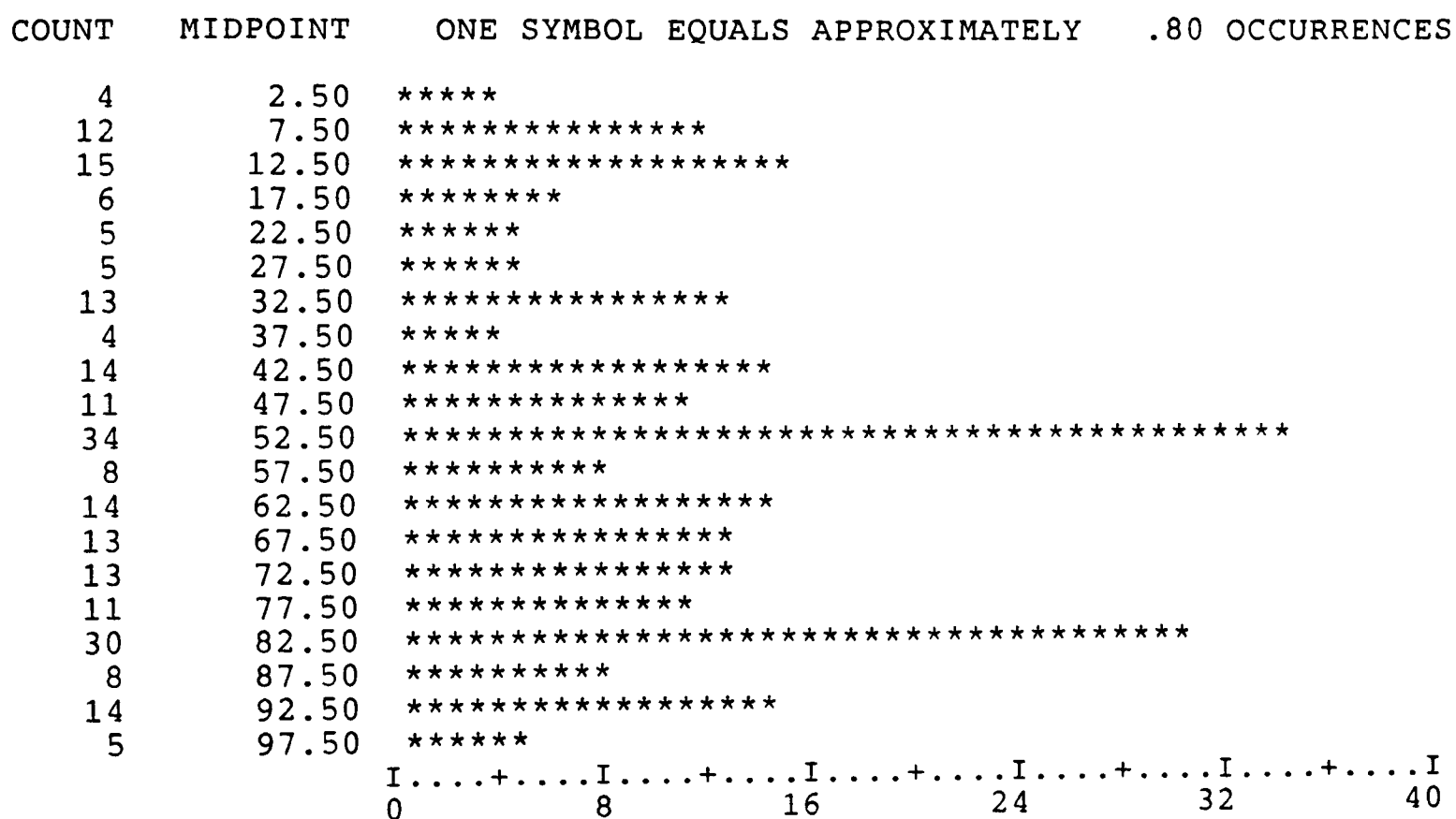


Figure B.8 Frequency distribution of the percentage residential land use estimated by the students

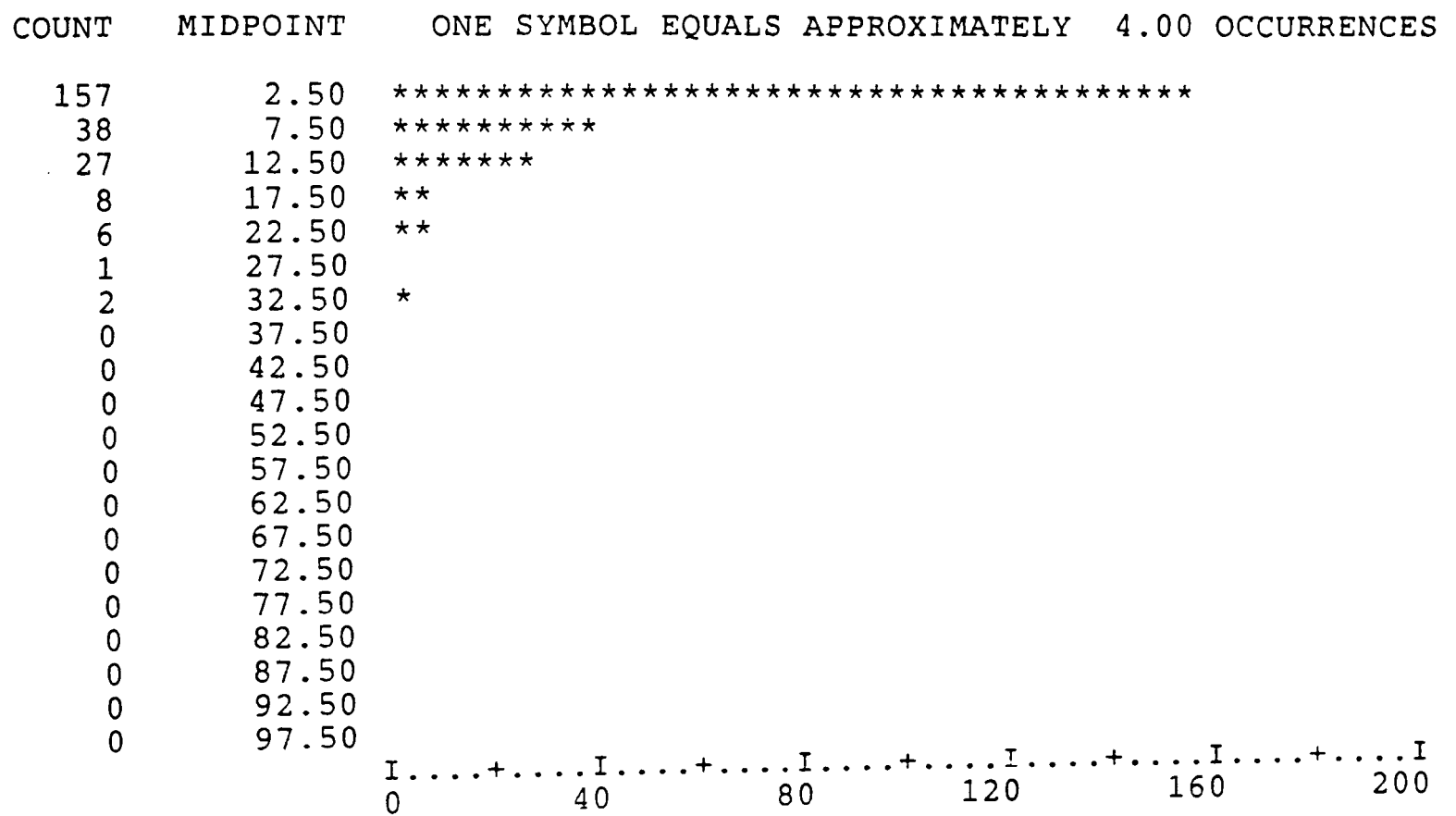


Figure B.9 Frequency distribution of the percentage commercial land use estimated by the students

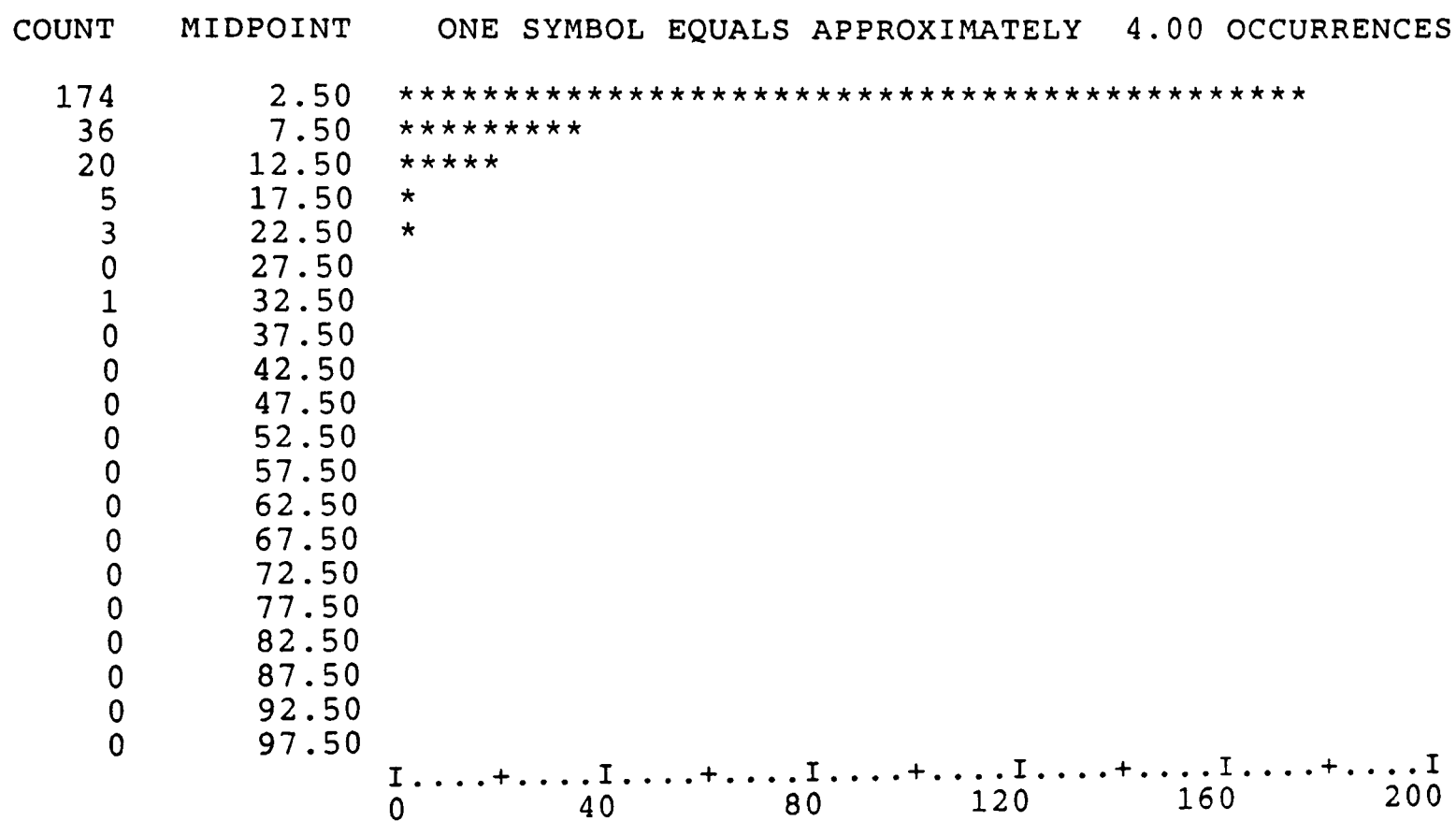


Figure B.10 Frequency distribution of the percentage institutional land use estimated by the students

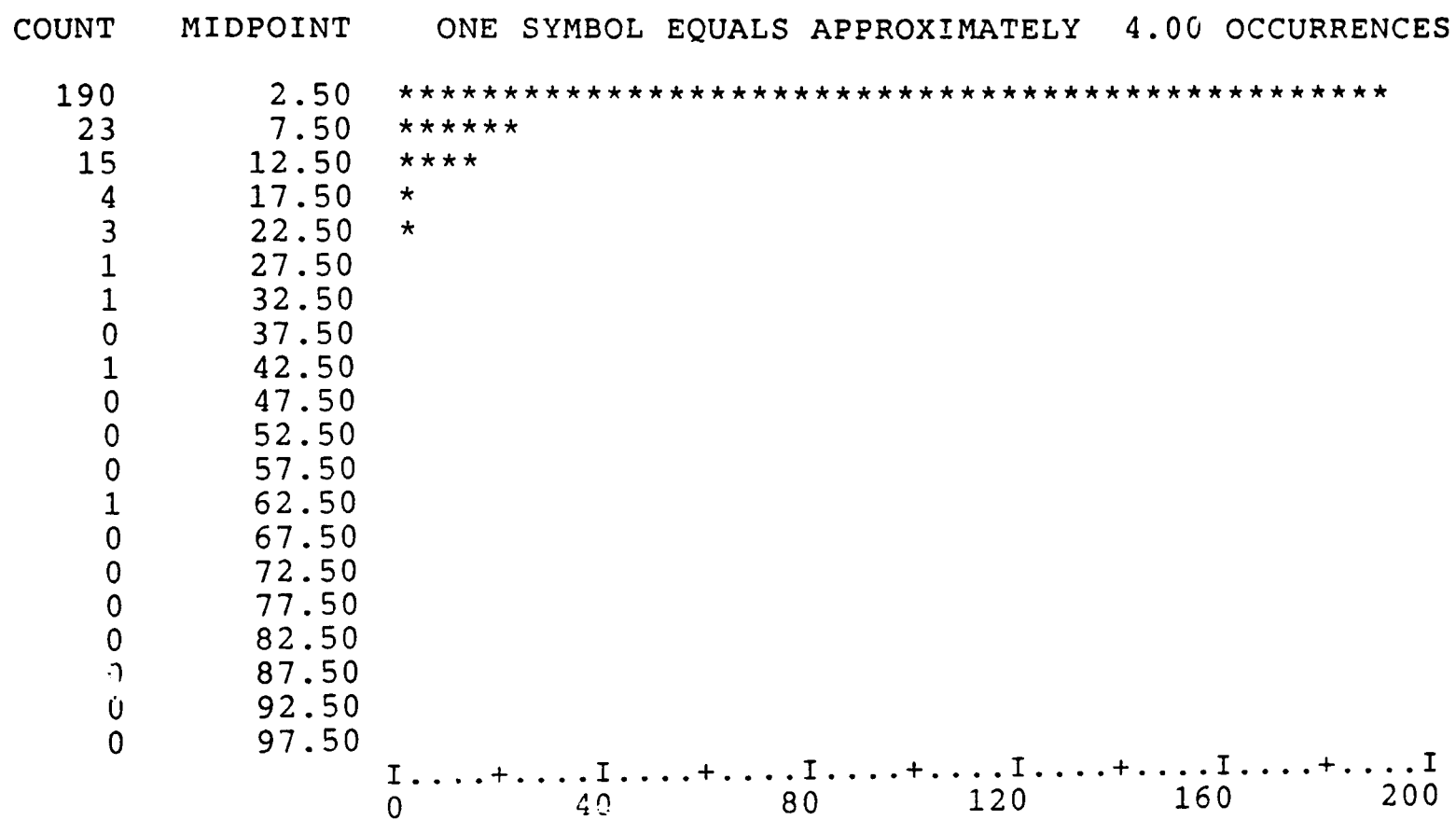


Figure B.11 Frequency distribution of the percentage industrial land use estimated by the students

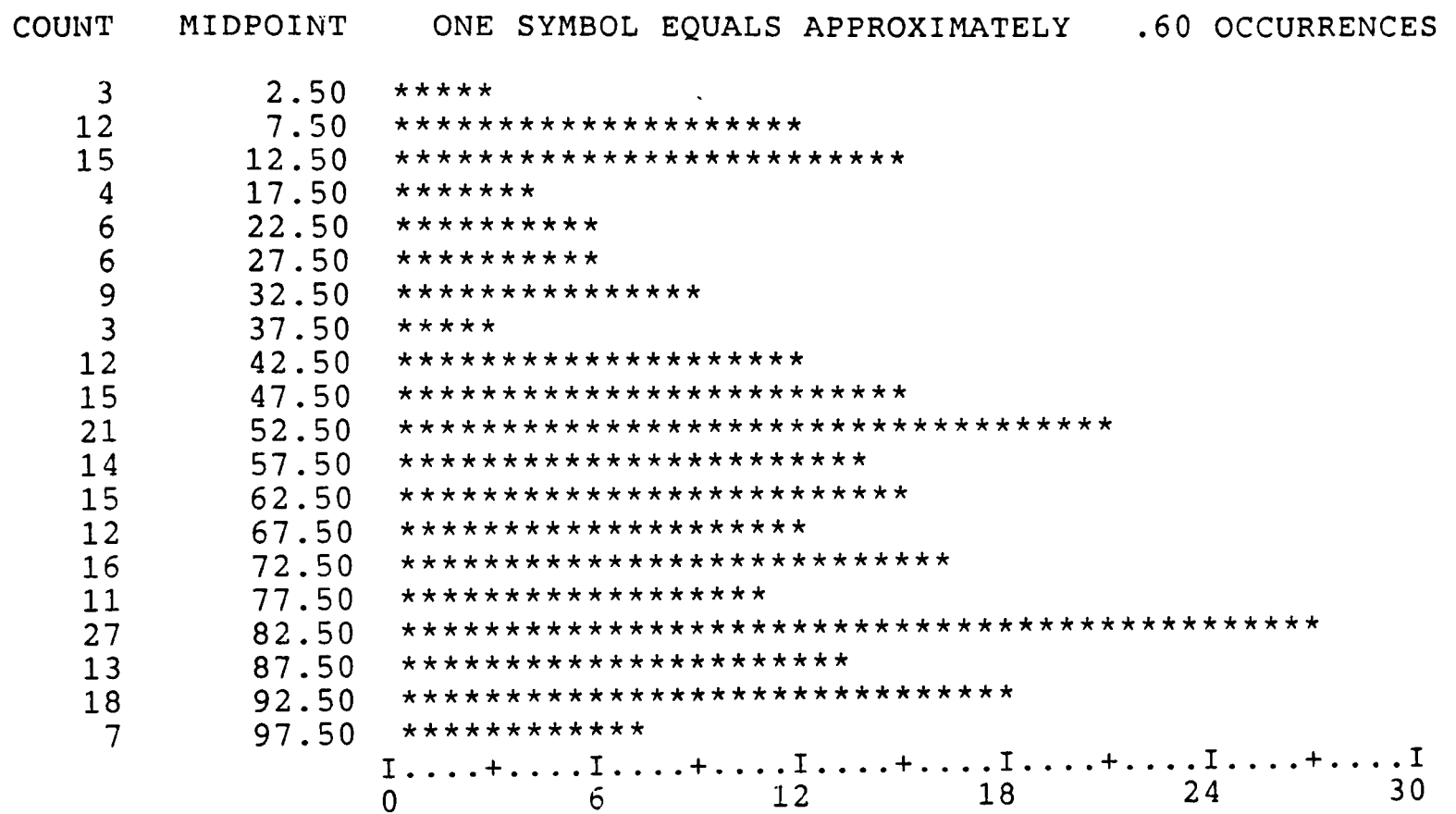


Figure B.12 Combined frequency distribution of the student estimates of percentages of residential and institutional land uses

Appendix C

Details of the national survey of smoke and sulphur dioxide

This appendix gives a summary of the measurement methods and data processing associated with the measurements of smoke and sulphur dioxide supplied by the Warren Spring Laboratory.

A summary of the air pollution data is also given in the following formats:

- Maps showing the spatial distribution of the various concentrations of smoke and sulphur dioxide.
- Air pollution levels classified by region, land use and smoke control.

C.1 Selection of monitoring sites

The national network of monitoring stations for smoke and sulphur dioxide 1961 - 1982 was based on the network of the Committee for Investigation of Atmospheric Pollution established in 1914. Additional monitoring sites were selected to meet the requirements of the Clean Air Act 1956. These monitoring sites were selected to be geographically representative, to cover towns of different populations, population densities, domestic heating habits, industrial and other activities, and of different meteorological conditions. The sites included two-hundred country sites. Some of the country sites were operated by the Central Electricity Generating Board around new and proposed power stations and others were situated in villages and country areas to complete the coverage of the United Kingdom.

Monitoring sites in each of the towns selected were chosen to represent as many of the area-types defined by the site environment codes listed in Section 3.3.4. However, practical monitoring stations could not always be found in all of the available area-types.

The exact position and number of monitoring sites have changed slightly from year to year between 1961 and 1982.

The distribution of the monitoring sites used to calibrated the proposed air pollution models and the associated levels of the pollutants smoke and sulphur dioxide are shown in Figures C.1 to C.8

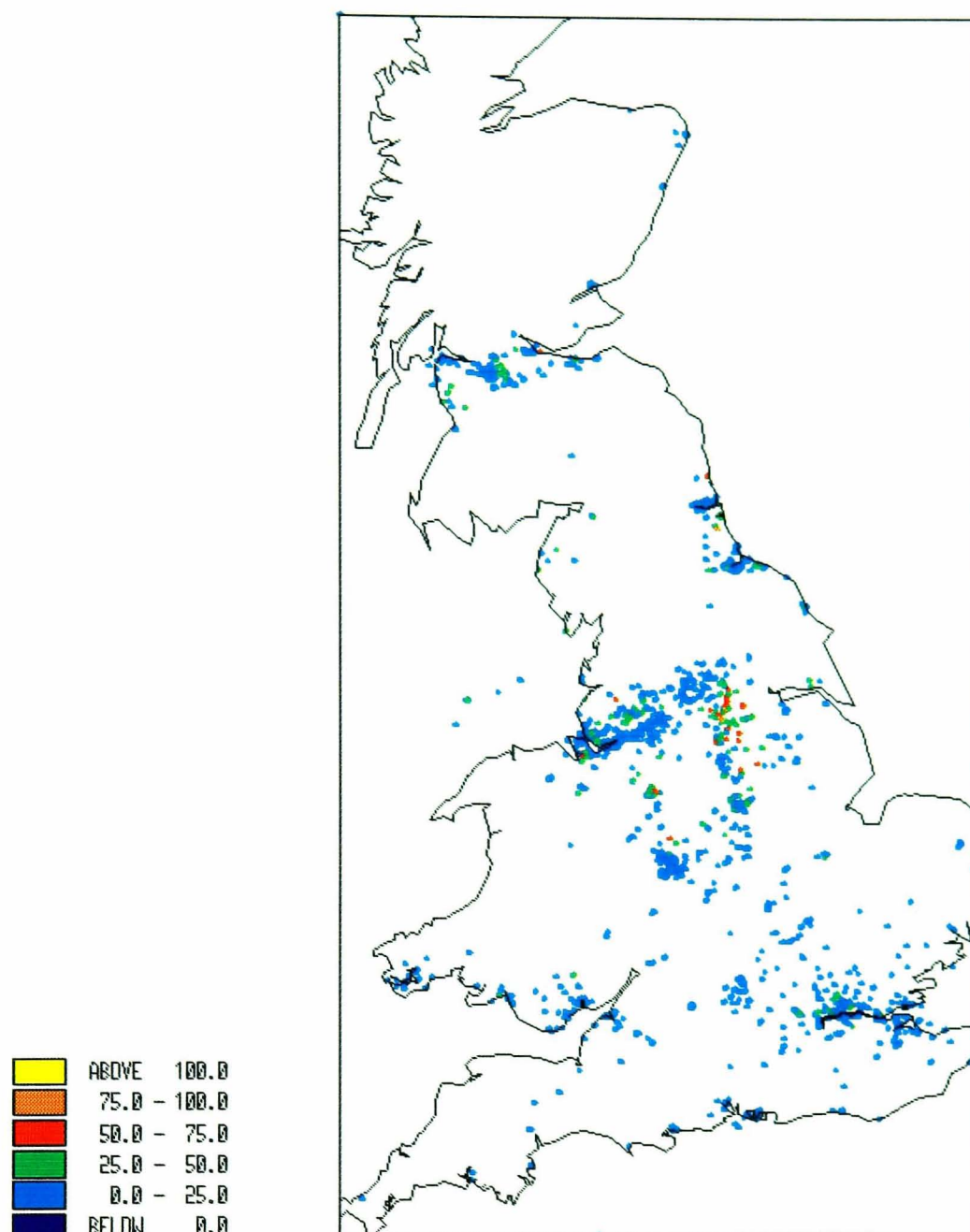


Figure C.1 Concentrations of smoke - winter median of daily values

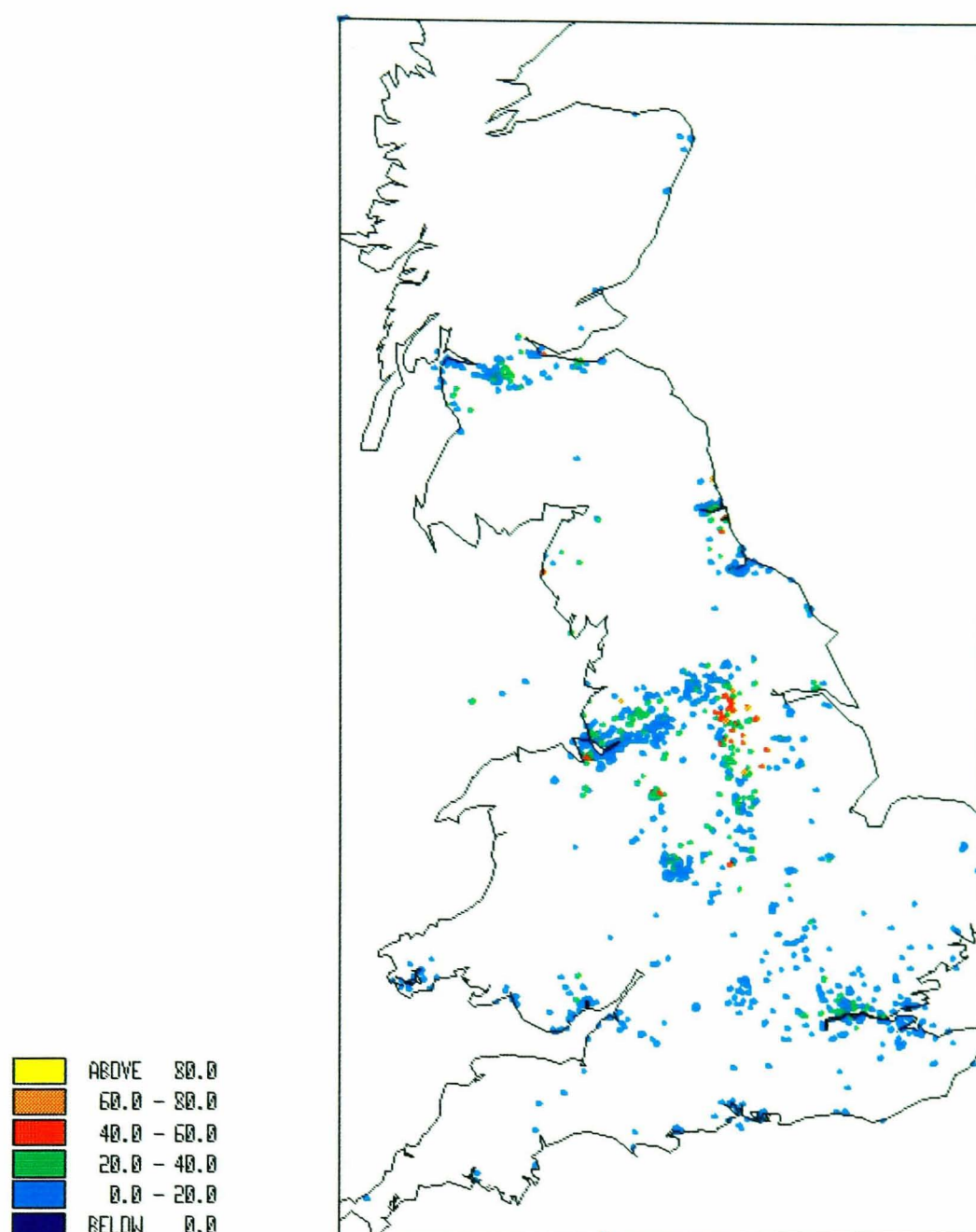


Figure C.2 Concentrations of smoke - yearly arithmetic mean of daily values

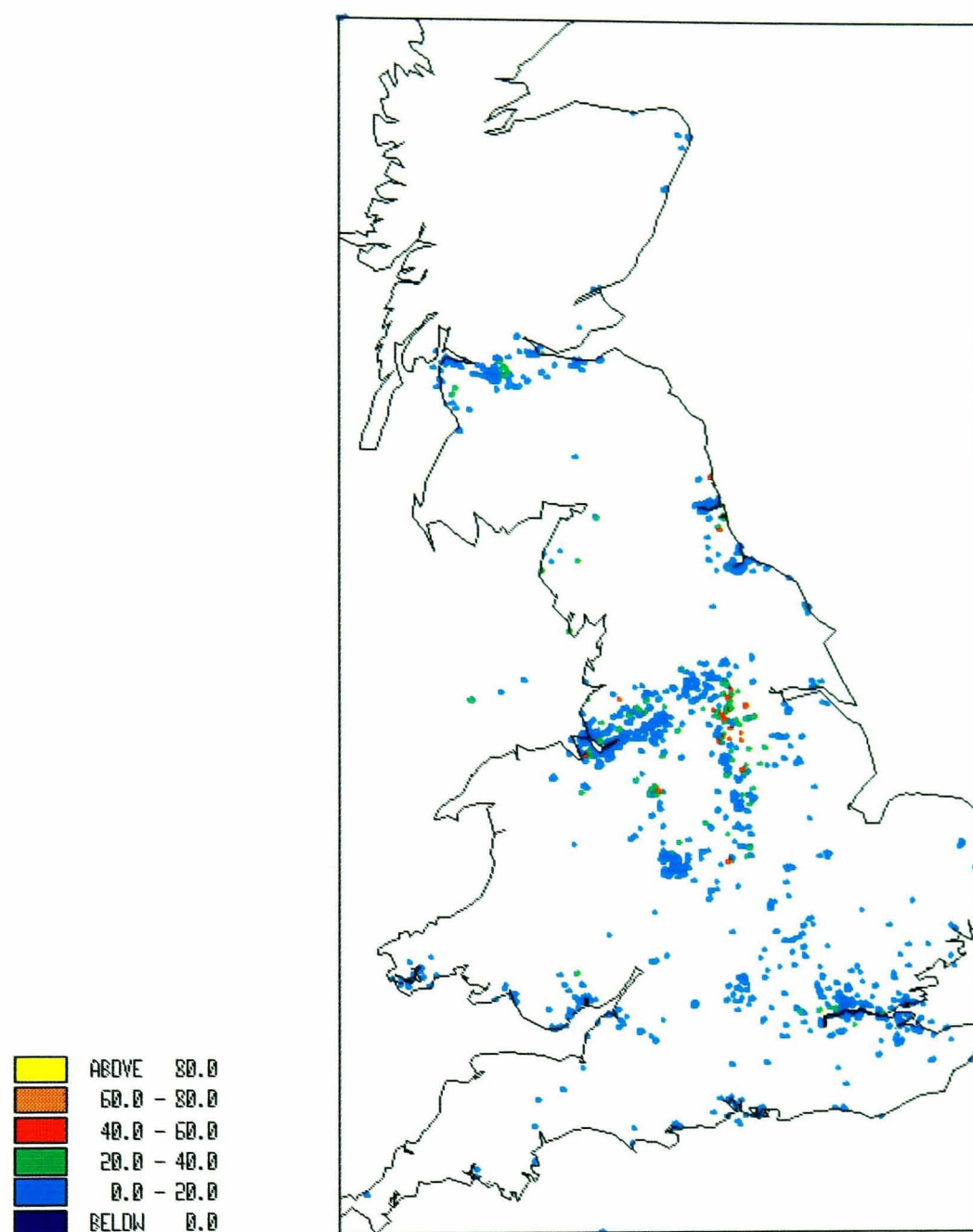


Figure C.3 Concentrations of smoke - yearly median of daily values

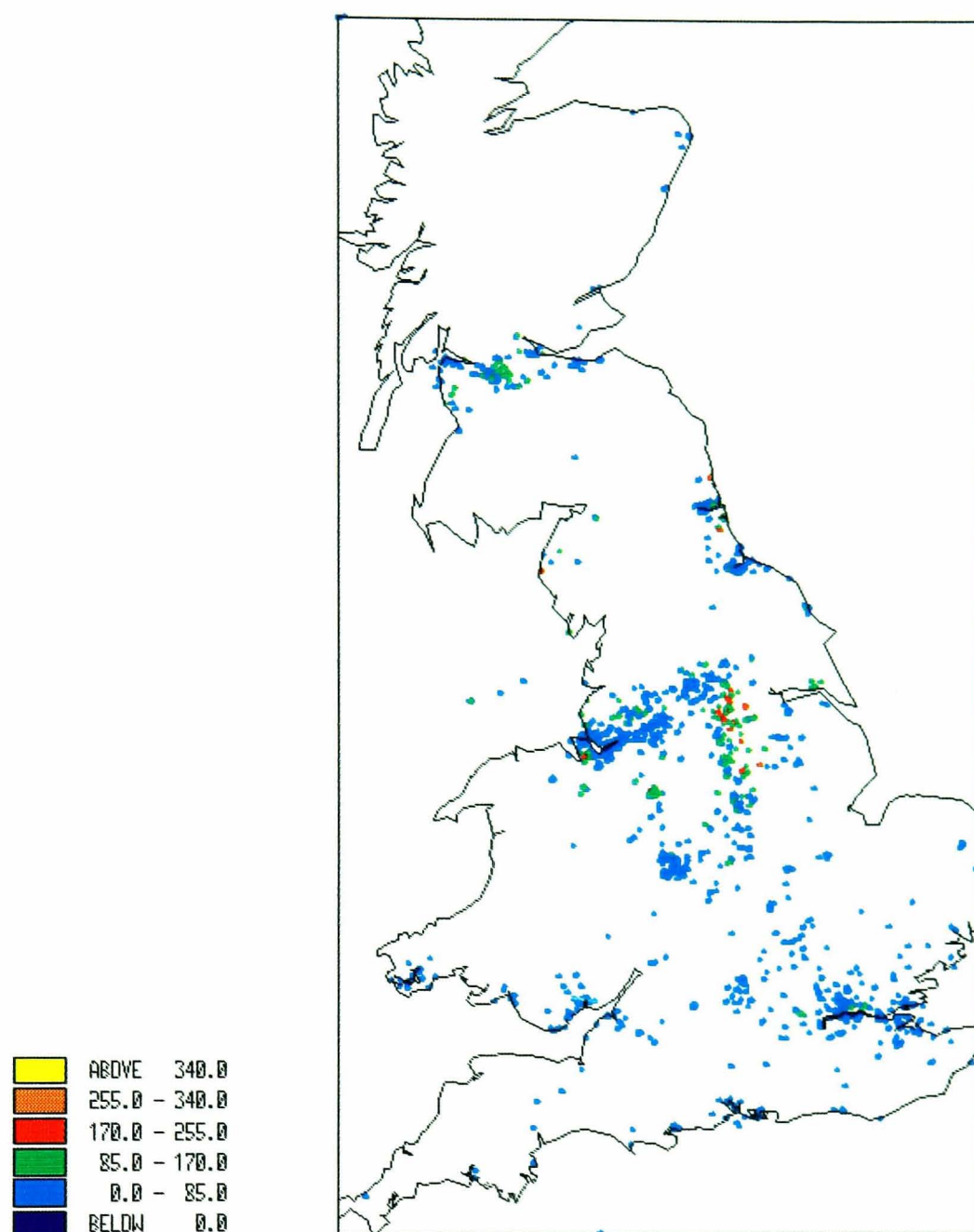


Figure C.4 Concentrations of smoke - yearly 98th percentile of daily values

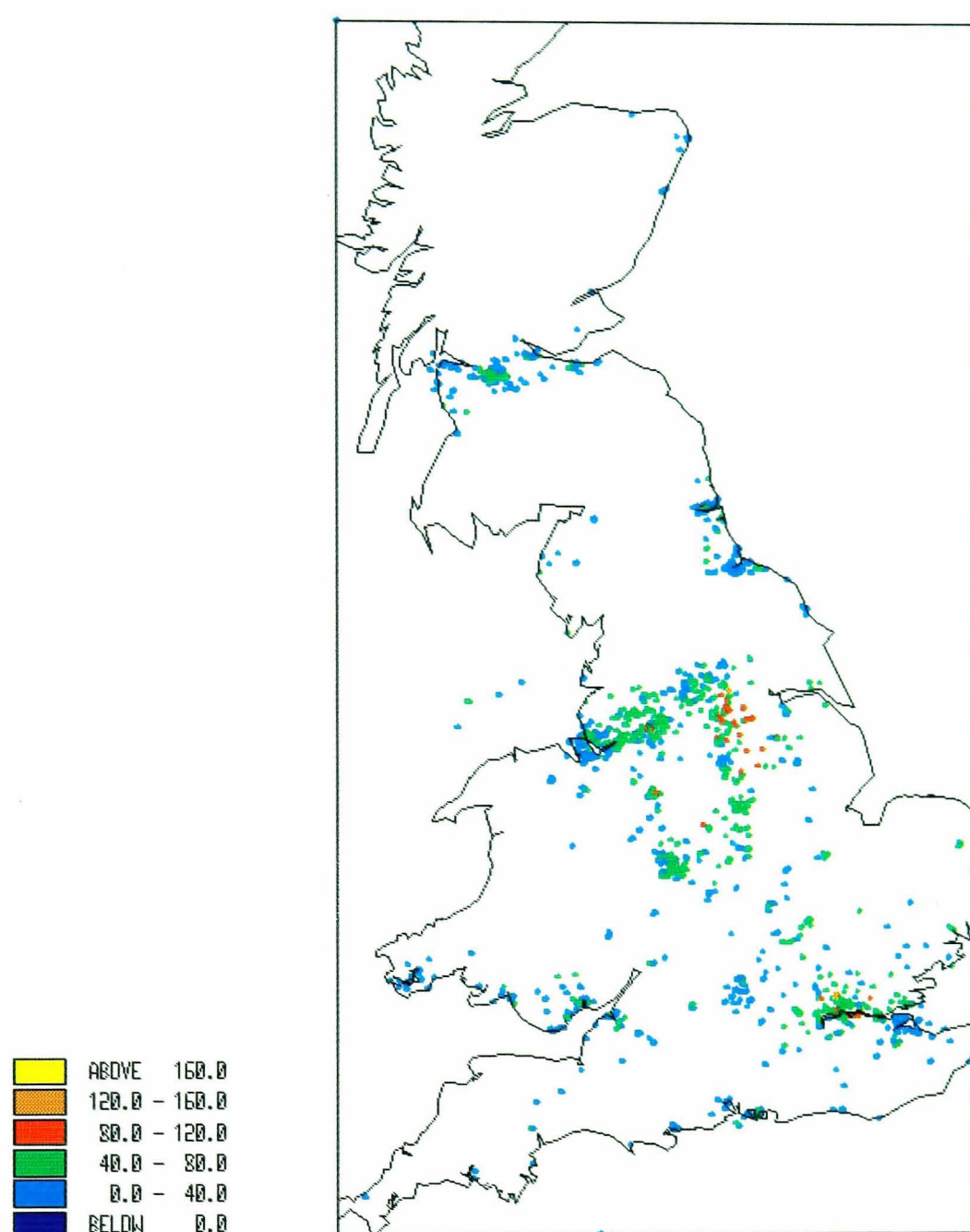


Figure C.5 Concentrations of sulphur dioxide - winter median of daily values

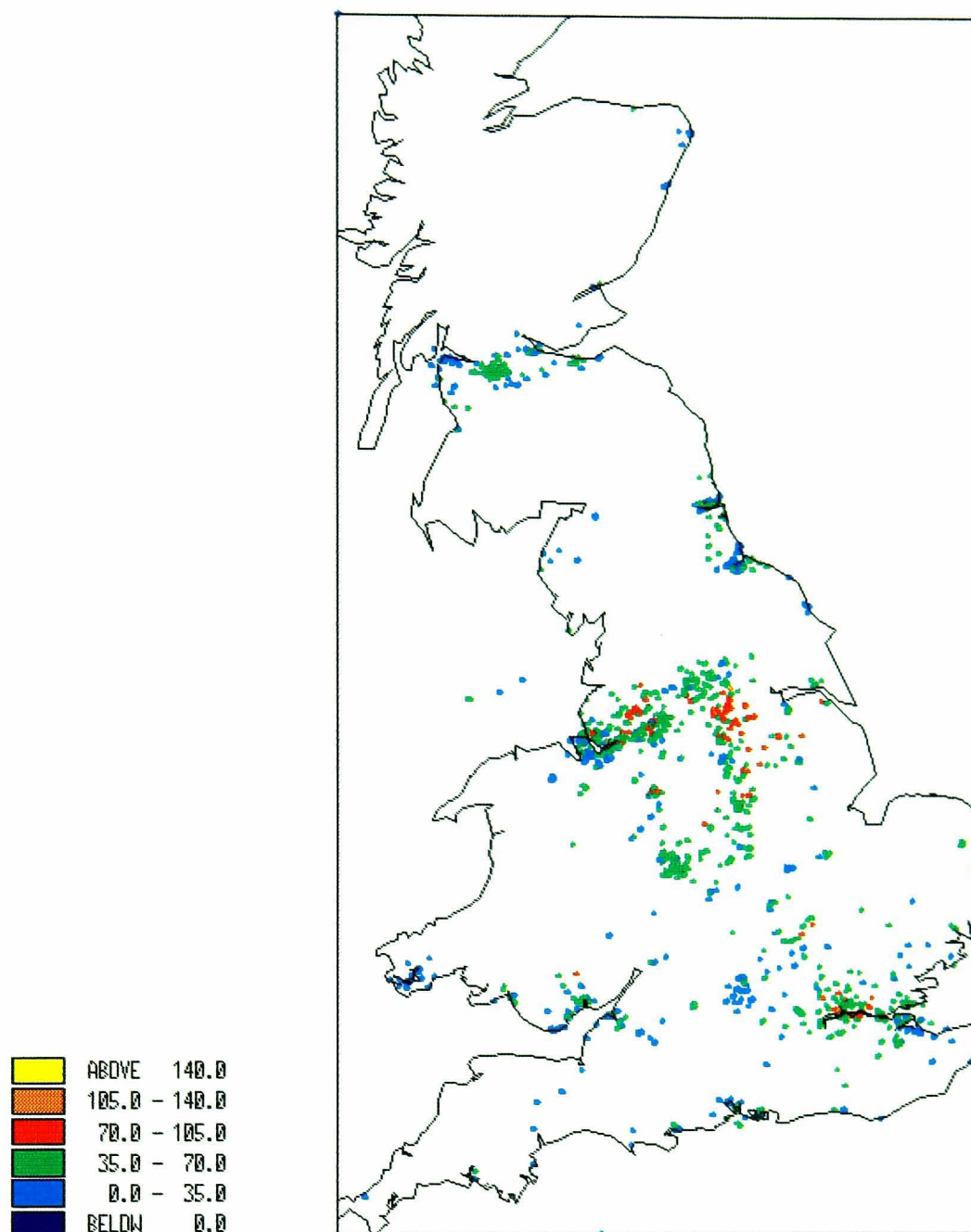


Figure C.6 Concentrations of sulphur dioxide - yearly arithmetic mean of daily values

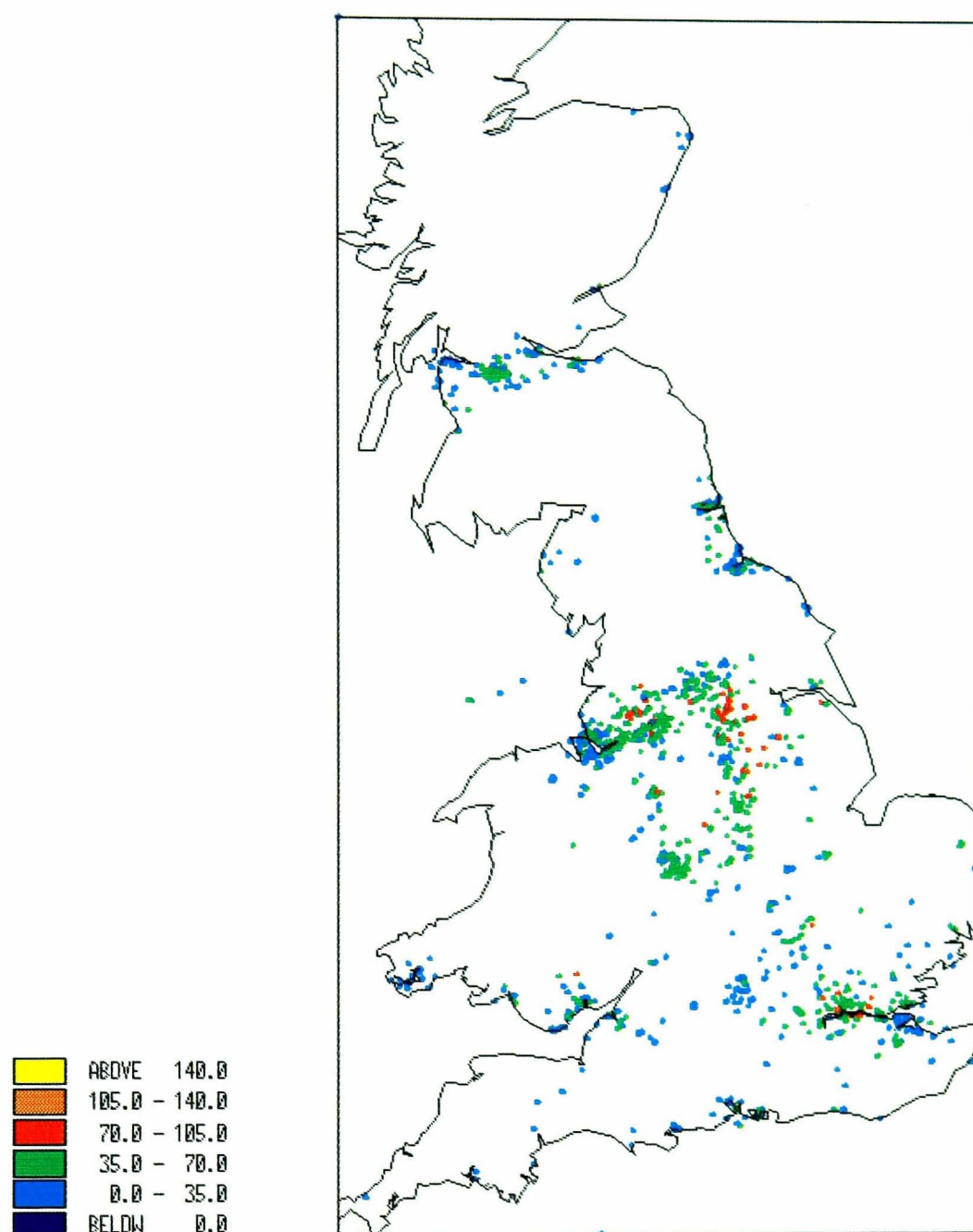


Figure C.7 Concentrations of sulphur dioxide - yearly median of daily values

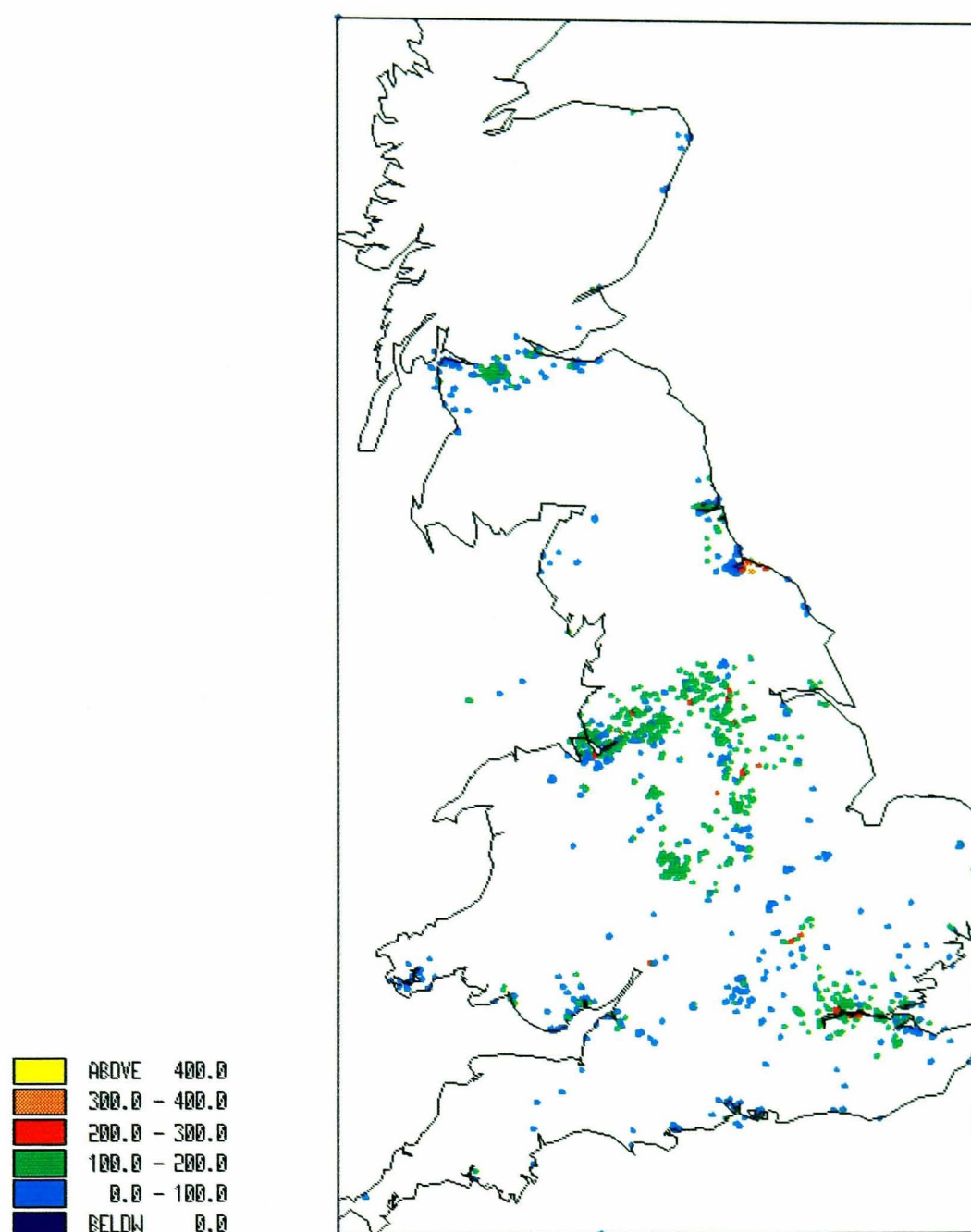


Figure C.8 Concentrations of sulphur dioxide - 98th percentile of daily values

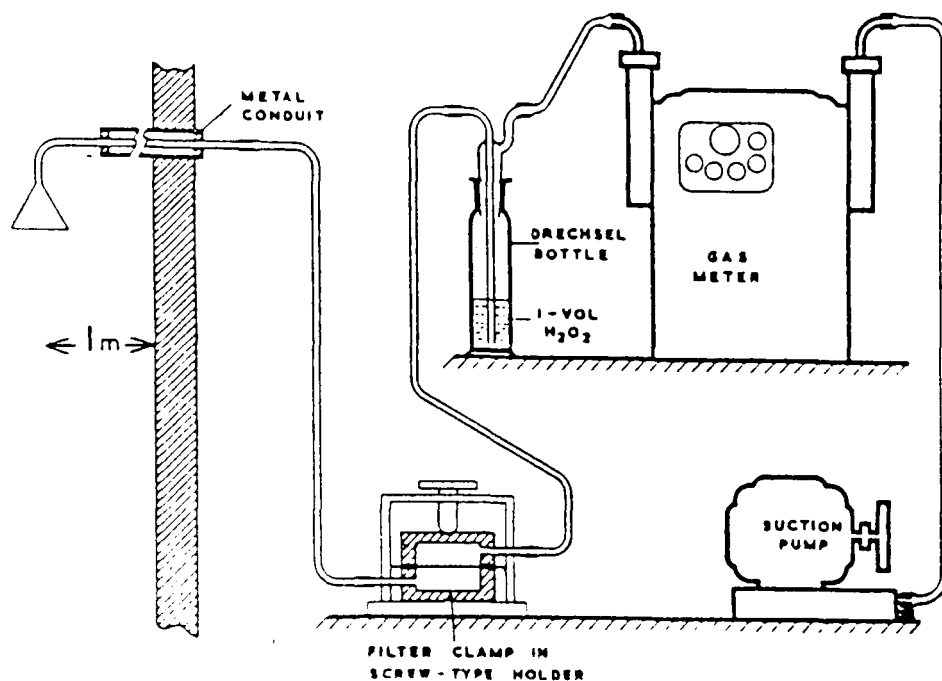


Figure C.9 Schematic arrangement of standard daily smoke and sulphur dioxide sampling apparatus (WSL 66).

C.2 Measurement Method

The measurement method used to monitor smoke and sulphur dioxide in the National Survey of Smoke and Sulphur dioxide is shown schematically in Figure C.9

The methods are described in British Standards:

1. BS 1747 Part 2 - smoke (BSI 69)
2. BS 1747 Part 3 - sulphur dioxide (BSI 69)

A sample of air is drawn, for a 24 hour period, through a cellulose filter paper and the staining measured by a reflectometer. The sample of air is then bubbled through a solution of dilute hydrogen peroxide which oxidises any sulphur dioxide to sulphuric acid. The concentration of sulphuric acid is determined by titration to pH 4.5

The values of smoke and sulphur dioxide concentrations are 24 hour average concentrations expressed in $\mu\text{g}/\text{m}^3$ (a gas meter having recorded how much air has been sampled each day).

The filter paper and hydrogen peroxide solution is replaced daily either manually or by an automatic valve that switches between sets of apparatus. The 8 port valve automatic apparatus allows a monitoring station to be operated for a

week without requiring servicing. The apparatus consists of eight sets of apparatus connected to an automatic valve that switches between the sets each day.

C.3 Accuracy of Sampling Method

A number of sampling errors may occur that result in the air sample not being truly representative of the conditions in the outside air. Errors may be due to the conditions at the air intake funnel or conditions between the air intake and the collection point.

The National Survey of Smoke and Sulphur Dioxide Instruction Manual (WSL 66) attempts to minimise the sampling errors by enabling a uniform sampling method to be applied throughout the network. However, errors do occur and the main sources of sampling error are discussed below.

Unrepresentative readings may occur if the sampling funnel is positioned within a few meters of source, such as traffic or chimneys or if it is obstructed, or is inverted so that it collects rainwater.

The proximity of traffic emissions is particularly significant for smoke measurements as traffic smoke is much blacker, weight for weight, than town smoke (WSL 72 and BAL 77).

If the gas sample passes through equipment that can absorb sulphur dioxide, e.g. rubber tubing, 'Araldite', soda glass, anodized aluminium clamps, then an under estimate of the sulphur dioxide concentration will occur.

Representative measurements depend on regular maintenance of the sampling equipment to ensure that it does not deteriorate, leak or become obstructed by insects etc.

Leakage of the sampling equipment may result in sampling of indoor air and, if the leak occurs between the flow meter and collection point (as shown in Figure C.9) it may results in over estimates of the volume of air sampled.

C.4 Accuracy and Reproducibility of the Measurement Methods

British Standard BS 1747 parts 2 and 3 give figures for the accuracy of the 'smoke shade' and 'sulphur dioxide bubbler' measurement techniques respectively. An accuracy of $\pm 10\%$ is given for smoke stains of $10 \mu\text{g}$ of deposited matter and replicate determinations of sulphur dioxide lie within the following limited of their mean:

$\mu\text{g}/\text{m}^3$ of SO_2	Maximum deviations
Up to 500	$\pm 20 \mu\text{g}$
Over 500	$\pm 4\%$

The OECD working party report (OEC 64) states that the sulphur dioxide measurement method is $\pm 10\%$ for concentrations greater than $100 \mu\text{g}/\text{m}^3$.

Warren Spring Laboratory have investigated the reproducibility of their measurement technique (WEA 62) and found that replicate measures of smoke and sulphur dioxide by various workers have coefficients of variation of 6% and 5 - 10% respectively for daily observations. They have also found that the mean difference between two instruments operating at the same site over a period of approximately one month is up to 5% for sulphur dioxide.

Errors that effect both measures of smoke and sulphur dioxide concentrations are associated with the accuracy of the gas meter. The main sources of error are:

- variations between accuracy of individual meters (approximately 3%),
- errors in reading the meter or recording the value,
- particulate build upon the filter paper causing back pressure in the 8 port valve equipment resulting in daily variations in the volume of air sampled.

Every effort is made by the Warren Spring Laboratory to avoid these errors by checking the data at the processing stage and ensuring that the appropriate size filter is used for the season and area's smoke characteristics.

C.5 Errors Affecting Measurements of Smoke

The reflectometer is used to measure the darkness of the smoke stain on the filter paper from the apparatus. A calibration curve is used to give the equivalent standard smoke concentration in $\mu\text{g}/\text{m}^3$ of air which is reproduced in Figure C.10. This figure is not a measure of the actual smoke concentration but for ordinary town smoke there is little difference between the actual smoke and the equivalent standard smoke concentrations.

Inaccuracies occur where the smoke is of a significantly different colour. Air rich in diesel smoke has a darker stain and air high in chalk or cement dust will be lighter in colour weight for weight.

Work by Ball and Hume (BAL 77) indicates that in London the smoke stain value is highly correlated with the daily mean lead concentration and less well correlated with the actual daily mean particulate concentrations measured using gravimetric methods. The results from this research are shown in Figure C.11.

A Warren Spring Laboratory study in 1966 (WSL 72) showed that 10% of the 989 filter papers examined gave inaccurate values of smoke concentrations of up to 25% (usually under estimated). The main cause of this error was poor maintenance of the reflectometer, careless insertion of the filter paper or using a filter size that was too small producing a stain that was too dark to obtain an accurate reading.

C.6 Errors Affecting Measures of Sulphur Dioxide

The sulphur dioxide measurement methods determines the air's acidity. In ordinary towns sulphur dioxide accounts for most of the air's acidity thus it is assumed that

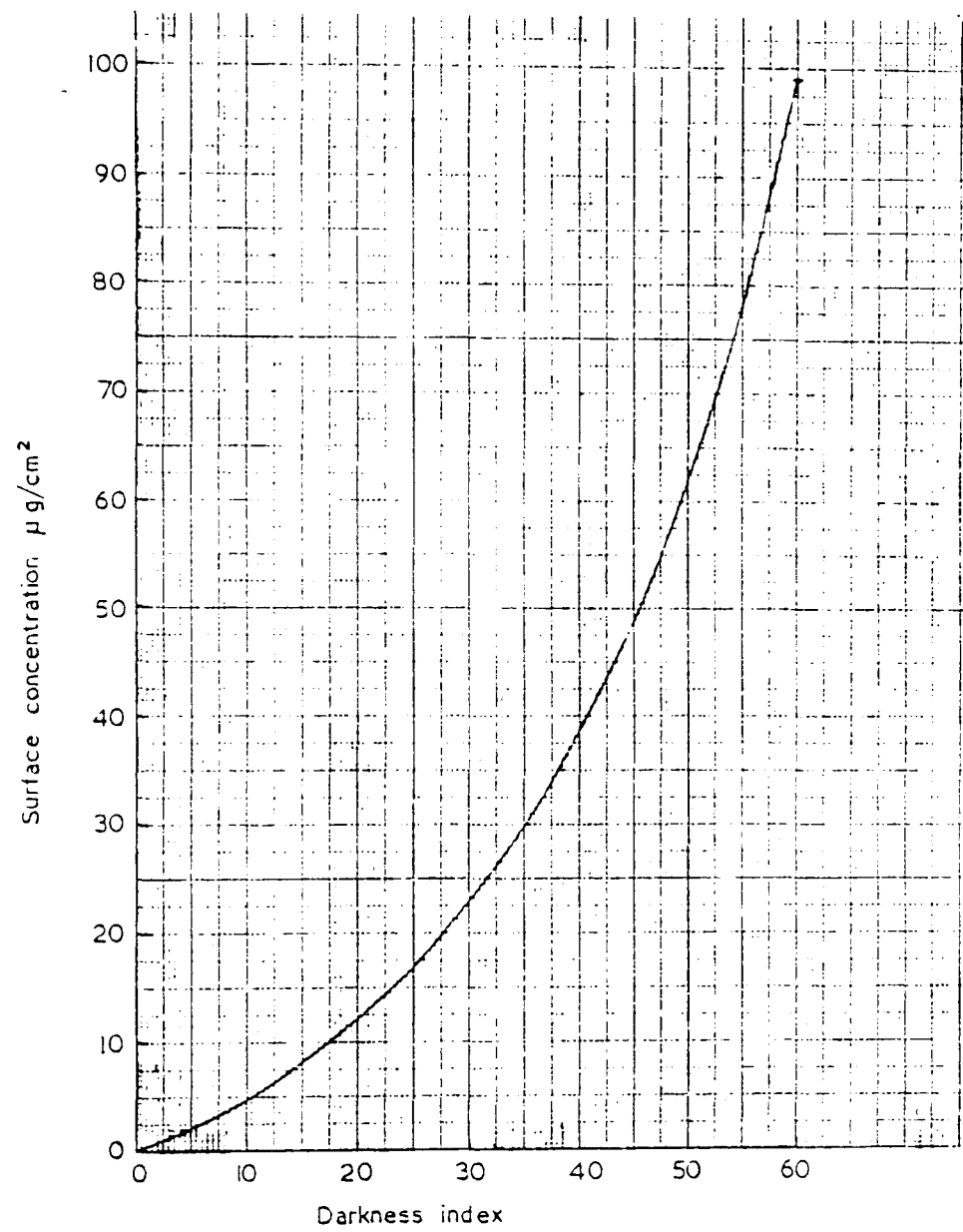


Figure C.10 British smoke calibration curve for 25mm. filter BS 1747 (BSI 69)

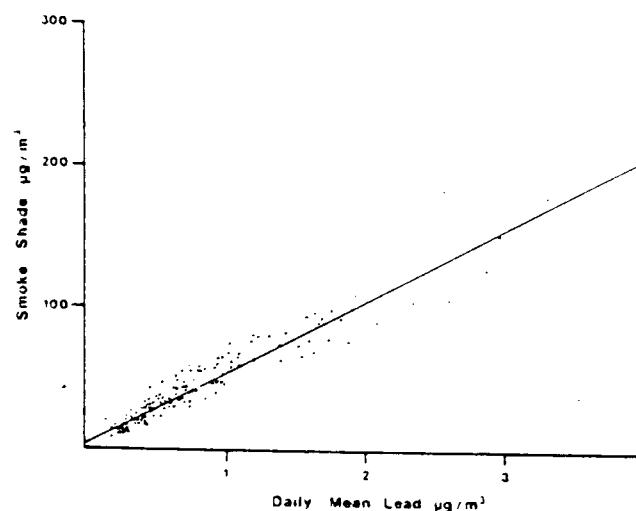


Figure C.11 Correlation between smoke shade and mean lead concentrations in London (BAL 77)

the acidity is entirely due to sulphur dioxide and the concentration of sulphur dioxide calculated and expressed as $\mu\text{g}/\text{m}^3$ of air.

Inaccuracies occur where the air is contaminated with other acidic chemicals (e.g. nitrogen dioxide) or alkaline pollutants (e.g. ammonia) or where alkaline particulate matter is deposited on the smoke stain filter paper.

Ammonia can cause under estimates of up to $80 \mu\text{g}/\text{m}^3$ in rural areas and $25 \mu\text{g}/\text{m}^3$ in urban areas on individual days.

Substantial errors may also occur due to the use of solutions of inaccurate molarity or poor quality distilled water.

Uncertainty in the filtration end point and limited accuracy of the method each introduce errors of up to $\pm 5 \mu\text{g}/\text{m}^3$. Evaporation of the dilute hydrogen peroxide solution may also introduce an error of up to $15 \mu\text{g}/\text{m}^3$ over estimates in summer months.

C.7 Data Supplied on Magnetic Tape

Warren Spring Laboratory in Stevenage (Department of Trade and Industry) supplied data on magnetic tape for all smoke and sulphur dioxide measurement sites monitored between April 1979 and March 1982.

Table C.1 gives the data supplied for each measurement site and Table C.2 gives the data supplied for each of the pollutants:

1. Summer smoke
2. Winter smoke
3. Yearly smoke

Table C.1 Measurement site data

Number of words in record: 256
 Site identity number
 Character 1 (one)
 Alphanumeric site identification
 Site environment code
 Local Authority District code
 County code
 Registrar General's Statistical Region code
 Co-operating Body code
 Recipient address code
 8-port valve code
 Alphanumeric O.S. grid reference
 Numeric O.S. grid reference, Easting
 Numeric O.S. grid reference, Northing Year e.g. 1979= 1979-80
 End of summer period, day number
 End of winter (year) period, day number
 Days over smoke /SO₂ limits, 100/350, summer
 Days over smoke/SO₂ limits, 100/250, summer
 Days over smoke/SO₂ limits, 250/250, summer
 Days over smoke/SO₂ limits, 250/500, summer
 Days over smoke/SO₂ limits, (as 22-25), winter
 Days over smoke/SO₂ limits, (as 22-25), annual

4. Summer sulphur dioxide

5. Yearly sulphur dioxide

at each of the sites. The site environment codes are given in Section 3.3.4.

No details were given of the numerical codes used to define the Local Authority districts, Counties or Registrar General's Statistical regions.

For National Survey purposes Warren Spring Laboratory defines a 'month' as a 28 or 35 day period approximating to the calendar months but rarely coinciding with them. The national survey 'year' is never April 1st to March 31st but a 364 or occasionally 357 or 371 day period matching these dates as near as possible. The beginning of the year (and summer period) is day 1. Thus the year 1980 is the period April 1980 to March 1981. This year is 364 days long with a winter period of 182 days.

Table C.2 Measurement site data for summer, winter and yearly measures of smoke and SO₂

Number of valid observations
Start day of longest gap in observations
Length of gap, days
Ditto for 2nd, 3rd and 4th longest gaps
Arithmetic mean, $\mu\text{g}/\text{m}^3$
Standard deviation, $\mu\text{g}/\text{m}^3$
Geometric mean, $\mu\text{g}/\text{m}^3$
Standard deviation of log concentrations ($\times 1000$)
Median, $\mu\text{g}/\text{m}^3$
1st percentile value, $\mu\text{g}/\text{m}^3$
5th percentile value, $\mu\text{g}/\text{m}^3$
20th percentile value, $\mu\text{g}/\text{m}^3$
50th percentile value, $\mu\text{g}/\text{m}^3$
80th percentile value, $\mu\text{g}/\text{m}^3$
90th percentile value, $\mu\text{g}/\text{m}^3$
95th percentile value, $\mu\text{g}/\text{m}^3$
98th percentile value, $\mu\text{g}/\text{m}^3$
99th percentile value, $\mu\text{g}/\text{m}^3$
Highest concentration, $\mu\text{g}/\text{m}^3$
Day number of highest concentration
Ditto for 2nd, 3rd, 4th, and 5th highest concentrations
No. of days over 100 smoke or 200 SO ₂
No. of days over 120 smoke or 250 SO ₂
No. of days over 200 smoke or 350 SO ₂
No. of days over 250 smoke or 500 SO ₂

C.8 Computation of Pollutant Parameters

The equations and methods used to compute the different pollutant parameters are given below.

C.8.1 Arithmetic Mean

$$A = \frac{\sum_{i=1}^n C_i}{N} \quad (\text{C.1})$$

Where:

A is the arithmetic mean
 C_i is the daily concentration for day i , and
 N is the number of values ($N \geq 10$)

C.8.2 Median

Warren Spring Laboratory sort the daily concentrations into ascending order of concentration value

$C_1, C_2, C_3, \dots, C_i, \dots, C_N$.

If N is even and ≥ 10

$$M = \frac{[C_{\frac{N}{2}} + C_{(\frac{N}{2}+1)}]}{2} \quad (\text{C.2})$$

or if N is odd and > 10

$$M = C_{(\frac{N}{2}+0.5)} \quad (\text{C.3})$$

Where:

M is the median
 C is the daily concentration in the ascending set, and
 N is the number of values

C.8.3 Percentiles

Daily concentrations are sorted by Warren Spring Laboratory into ascending order of concentration value as above. The associated percentile value is found using the following equation:

$$P_i = \frac{i}{(N+1)} \times 100 \quad (\text{C.4})$$

Where:

P_i is the percentile for the i th concentration
in the sorted set, that is, $P_i\%$ of the concentration
will be $\leq C_i$, and
 N is the number of values ($N \geq 10$)

The concentrations relevant to the fixed percentiles values are obtained by linear interpolation between the concentration values for the nearest percentile values on either side. For example, in the sets:

$$\begin{aligned} P_1, P_2, P_3, \dots, P_i, \dots, 98.8, 99.3, \dots, P_N. \\ C_1, C_2, C_3, \dots, C_i, \dots, 150, 160, \dots, C_N. \end{aligned}$$

the 99th. percentile would be $154 \mu\text{g}/\text{m}^3$.

If the required percentile value is not available, the value is set to zero e.g. if the number of results available is only 39, the highest percentile value would be $(39/40) \times 100 = 97.5$ so that the values for the required 98th. and 99th. percentiles would be recorded as zero, as would be the 1st. percentile.

All alkaline sulphur dioxide measurement readings are treated as zero concentrations and included as valid results.

In computing the pollutant parameters, Warren Spring Laboratory set a minimum of ten daily values within the relevant period. If the number of measurements falls below ten the computed parameters are set to zero. No other selection or rejection criteria are applied to the data.

C.9 Summary Air Pollution Statistics

The following tables contain summary statistics for the National Survey of Air Pollution data for the year April 1980 to March 1981.

Table C.3 Smoke winter median of daily values

Variable	MEAN	STD DEV	CASES
FOR ENTIRE POPULATION	17.4528	11.5184	1018
Open space	9.2353	7.2592	102
No smoke control	9.2353	7.2592	102
South east	8.5652	3.3551	23
Scotland	5.8571	4.3475	14
South West	1.0000	.0000	1
North West	10.3750	4.5962	8
North East	19.9091	13.3000	11
Northern Ireland	5.8000	1.0954	5
Midlands	12.9500	2.9996	20
Wales	2.6111	2.2265	18
East Anglia	12.5000	2.1213	2
Residential	17.0783	11.4219	383
No smoke control	18.5689	13.5336	225
South east	10.7561	3.4697	41
Scotland	14.8800	8.7717	25
South West	9.6364	3.9312	11
North West	20.5000	8.4744	28
North East	28.8372	19.7845	43
Northern Ireland	26.8333	19.9856	12
Midlands	19.1622	11.0668	37
Wales	13.6667	9.5732	18
East Anglia	18.3333	4.1312	6
London	14.5000	3.1091	4
Smoke control	14.9557	6.9560	158
South east	13.9167	6.5012	12
Scotland	15.3684	7.1586	19
South West	10.0000	5.1962	3
North West	15.2941	4.1380	34
North East	12.4048	8.4393	42
Northern Ireland	12.0000	6.0828	3
Midlands	17.0714	5.0606	14
Wales	18.0000	.0000	1
London	18.0000	7.2397	30

Table C.4 Smoke winter median of daily values - continued

Variable	MEAN	STD DEV	CASES
Commercial	18.1296	7.6579	54
No smoke control	17.0000	8.1056	21
South east	9.5000	4.9497	2
Scotland	27.5000	9.1924	2
South West	13.3333	2.7325	6
North West	21.0000	.0000	1
North East	31.0000	15.5563	2
Midlands	14.0000	3.6056	3
Wales	17.0000	5.6569	2
East Anglia	14.0000	.0000	1
London	15.0000	1.4142	2
Smoke control	18.8485	7.3956	33
South east	21.3333	15.3731	3
Scotland	16.0000	15.5563	2
South West	12.5000	.7071	2
North West	24.0000	6.4807	4
North East	19.1429	7.0576	7
Midlands	21.2000	6.9785	5
Wales	18.0000	.0000	1
East Anglia	13.0000	.0000	1
London	16.7500	3.6936	8
Industrial	16.5000	7.3585	18
No smoke control	16.1333	7.3860	15
South east	18.6667	10.9697	3
North West	16.5714	6.1875	7
North East	10.5000	1.2910	4
London	28.0000	.0000	1
Smoke control	18.3333	8.5049	3
North East	28.0000	.0000	1
Midlands	15.0000	.0000	1
London	12.0000	.0000	1

Table C.5 Smoke winter median of daily values - continued

Variable	MEAN	STD DEV	CASES
Residential/industrial	20.7371	11.9543	232
No smoke control	22.8832	13.6883	137
South east	14.2143	4.9796	14
Scotland	22.2381	11.4626	21
South West	9.8000	1.7889	5
North West	22.1176	6.2638	17
North East	30.0345	17.2098	29
Northern Ireland	32.1429	20.3177	7
Midlands	24.6129	13.2556	31
Wales	13.8182	8.7042	11
East Anglia	16.5000	2.1213	2
Smoke control	17.6421	7.9812	95
South east	13.5000	.7071	2
Scotland	16.1429	5.6413	14
North West	16.8214	4.4310	28
North East	17.0385	9.9418	26
Midlands	20.3333	12.1401	15
East Anglia	14.0000	.0000	1
London	21.1111	4.8074	9
Residential/commercial/industrial	18.3275	12.0435	229
No smoke control	18.6932	13.2340	176
South east	12.2857	4.6860	49
Scotland	19.3182	10.7676	22
South West	9.0000	4.5704	10
North West	28.4615	13.9798	13
North East	27.7097	20.2751	31
Northern Ireland	25.2500	13.5739	4
Midlands	20.8000	10.6751	30
Wales	12.2857	7.8292	14
East Anglia	15.6667	2.5166	3
Smoke control	17.1132	6.6785	53
South east	15.0000	4.2426	2
Scotland	12.6667	6.6583	3
South West	4.0000	.0000	1
North West	16.9375	5.7789	16
North East	16.5000	8.1971	14
Northern Ireland	31.0000	.0000	1
Midlands	19.4545	5.5202	11
London	17.6000	2.8810	5

TOTAL CASES = 1025

387

MISSING CASES = 7 OR 0.7 PCT.

Table C.6 Smoke yearly arithmetic mean of daily values

Variable	MEAN	STD DEV	CASES
FOR ENTIRE POPULATION	17.5298	10.2449	1006
Open space	9.8288	6.3459	111
No smoke control	9.8288	6.3459	111
South east	8.5714	2.4560	28
Scotland	6.6429	4.3254	14
South West	4.0000	.0000	1
North West	10.0000	3.9772	12
North East	20.5833	10.5955	12
Northern Ireland	6.8000	1.3038	5
Midlands	12.9000	2.6735	20
Wales	4.1176	1.8669	17
East Anglia	12.5000	2.1213	2
Residential	17.2766	10.0191	376
No smoke control	18.3604	11.8561	222
South east	11.3111	3.6421	45
Scotland	14.2400	7.7043	25
South West	11.4545	3.6977	11
North West	19.9286	8.0458	28
North East	27.6429	17.1931	42
Northern Ireland	26.8000	15.4402	10
Midlands	20.0556	10.2649	36
Wales	14.2500	8.8053	16
East Anglia	16.6667	2.8048	6
London	16.0000	3.4641	3
Smoke control	15.7143	6.2316	154
South east	14.2727	6.0182	11
Scotland	17.0526	6.5868	19
South West	15.0000	7.0711	2
North West	15.9118	3.9952	34
North East	14.1190	8.3146	42
Northern Ireland	11.0000	5.2915	3
Midlands	16.3333	4.5461	15
Wales	18.0000	.0000	1
London	17.7407	5.1410	27

Table C.7 Smoke yearly arithmetic mean of daily values - continued

Variable	MEAN	STD DEV	CASES
Commercial	18.7115	6.7223	52
No smoke control	17.7895	7.1070	19
South east	11.0000	4.2426	2
Scotland	23.5000	3.5355	2
South West	14.6000	2.8810	5
North West	20.0000	.0000	1
North East	32.0000	12.7279	2
Midlands	15.3333	2.5166	3
Wales	17.5000	4.9497	2
East Anglia	16.0000	.0000	1
London	15.0000	.0000	1
Smoke control	19.2424	6.5433	33
South east	20.3333	13.6504	3
Scotland	17.0000	14.1421	2
South West	14.0000	1.4142	2
North West	23.0000	4.1633	4
North East	20.7143	6.7259	7
Midlands	20.8000	6.0166	5
Wales	17.0000	.0000	1
East Anglia	12.0000	.0000	1
London	17.7500	3.7702	8
Industrial	17.3043	9.9153	23
No smoke control	16.9000	10.0572	20
South east	18.0000	10.8167	3
Scotland	5.0000	.0000	1
North West	16.0000	6.2650	9
North East	12.5000	2.0817	4
Midlands	49.0000	.0000	1
London	18.0000	9.8995	2
Smoke control	20.0000	10.3923	3
North East	32.0000	.0000	1
Midlands	14.0000	.0000	1
London	14.0000	.0000	1

Table C.8 Smoke yearly arithmetic mean of daily values - continued

Variable	MEAN	STD DEV	CASES
Residential/industrial	20.8914	10.4245	221
No smoke control	22.1923	12.0214	130
South east	13.2222	4.5491	9
Scotland	21.7143	9.9857	21
South West	11.4000	2.1909	5
North West	21.1875	5.0361	16
North East	28.8710	15.6668	31
Northern Ireland	30.2857	17.9696	7
Midlands	21.7667	9.8250	30
Wales	13.5556	2.7437	9
East Anglia	16.0000	.0000	2
Smoke control	19.0330	7.2502	91
South east	15.0000	.0000	2
Scotland	17.1538	4.8278	13
North West	18.0000	4.0988	26
North East	20.3600	10.0162	25
Midlands	20.0625	9.3128	16
East Anglia	12.0000	.0000	1
London	21.1250	3.1820	8
Residential/commercial/industrial	18.2063	10.7709	223
No smoke control	18.2931	11.7577	174
South east	12.4375	4.0837	48
Scotland	17.9130	8.6124	23
South West	9.9167	3.0883	12
North West	28.9167	14.2603	12
North East	26.7333	17.1463	30
Northern Ireland	24.6667	15.5349	3
Midlands	20.4839	9.8450	31
Wales	12.8333	7.2843	12
East Anglia	14.3333	.5774	3
Smoke control	17.8980	6.1787	49
South east	16.0000	4.2426	2
Scotland	14.0000	5.5678	3
South West	9.0000	1.4142	2
North West	17.5000	5.6125	14
North East	18.9231	6.8855	13
Northern Ireland	28.0000	.0000	1
Midlands	19.2500	6.1515	12
London	17.5000	2.1213	2

390

TOTAL CASES = 1013
MISSING CASES = 7 OR 0.7 PCT.

Table C.9 Smoke yearly median of daily values

Variable	MEAN	STD DEV	CASES
FOR ENTIRE POPULATION	13.4851	8.2701	1006
Open space	7.2072	5.0634	111
No smoke control	7.2072	5.0634	111
South east	6.4286	1.9707	28
Scotland	4.9286	3.3847	14
South West	1.0000	.0000	1
North West	6.8333	2.8551	12
North East	15.5833	8.7538	12
Northern Ireland	4.8000	.8367	5
Midlands	9.7000	2.1546	20
Wales	2.6471	1.7657	17
East Anglia	9.0000	2.8284	2
Residential	13.0718	7.9120	376
No smoke control	13.9054	9.3186	222
South east	8.4000	3.0181	45
Scotland	10.6800	5.9071	25
South West	8.4545	2.8413	11
North West	14.6429	6.4648	28
North East	21.0714	13.2525	42
Northern Ireland	21.2000	12.4079	10
Midlands	15.5556	8.2616	36
Wales	10.5625	7.1830	16
East Anglia	12.6667	2.3381	6
London	12.3333	3.0551	3
Smoke control	11.8701	5.0536	154
South east	11.0000	5.3104	11
Scotland	11.6842	4.5467	19
South West	10.5000	6.3640	2
North West	12.1471	3.7184	34
North East	10.6905	6.6972	42
Northern Ireland	8.3333	3.7859	3
Midlands	12.6000	3.5817	15
Wales	14.0000	.0000	1
London	13.8519	4.2940	27

Table C.10 Smoke yearly median of daily values - continued

Variable	MEAN	STD DEV	CASES
Commercial	15.0769	5.5866	52
No smoke control	13.7368	5.5462	19
South east	8.5000	3.5355	2
Scotland	19.0000	1.4142	2
South West	10.8000	2.2804	5
North West	16.0000	.0000	1
North East	24.5000	9.1924	2
Midlands	12.3333	2.5166	3
Wales	13.0000	4.2426	2
East Anglia	12.0000	.0000	1
London	12.0000	.0000	1
Smoke control	15.8485	5.5460	33
South east	17.3333	11.9304	3
Scotland	13.5000	12.0208	2
South West	11.5000	.7071	2
North West	17.7500	2.9861	4
North East	17.1429	5.8716	7
Midlands	16.8000	5.0695	5
Wales	14.0000	.0000	1
East Anglia	10.0000	.0000	1
London	15.2500	3.6154	8
Industrial	14.5652	9.5481	23
No smoke control	14.4500	9.9020	20
South east	15.0000	9.1652	3
Scotland	5.0000	.0000	1
North West	13.5556	6.9121	9
North East	10.0000	1.1547	4
Midlands	47.0000	.0000	1
London	15.0000	8.4853	2
Smoke control	15.3333	8.3865	3
North East	25.0000	.0000	1
Midlands	11.0000	.0000	1
London	10.0000	.0000	1

Table C.11 Smoke yearly median of daily values - continued

Variable	MEAN	STD DEV	CASES
Residential/industrial	16.2172	8.5343	221
No smoke control	17.0923	9.6677	130
South east	9.6667	3.9686	9
Scotland	15.7619	7.7454	21
South West	8.2000	2.1679	5
North West	16.0000	5.0596	16
North East	22.7419	12.8192	31
Northern Ireland	23.5714	13.7702	7
Midlands	17.2000	7.3738	30
Wales	10.7778	2.2791	9
East Anglia	12.0000	.0000	2
Smoke control	14.9670	6.4333	91
South east	12.0000	.0000	2
Scotland	12.6923	3.4733	13
North West	14.1154	3.6368	26
North East	16.3200	9.2813	25
Midlands	15.7500	7.7330	16
East Anglia	10.0000	.0000	1
London	17.0000	3.1168	8
Residential/commercial/industrial	14.1166	8.6172	223
No smoke control	14.1897	9.3564	174
South east	9.7917	3.4822	48
Scotland	13.3913	6.6315	23
South West	7.4167	2.5746	12
North West	23.3333	13.2688	12
North East	20.2333	13.1901	30
Northern Ireland	19.0000	13.4536	3
Midlands	16.0645	7.6939	31
Wales	10.5000	6.4031	12
East Anglia	11.3333	1.5275	3
Smoke control	13.8571	5.2757	49
South east	11.5000	3.5355	2
Scotland	9.0000	3.6056	3
South West	6.0000	2.8284	2
North West	13.9286	5.1510	14
North East	14.6923	5.7791	13
Northern Ireland	21.0000	.0000	1
Midlands	15.2500	4.8077	12
London	13.5000	.7071	2

TOTAL CASES = 1013

393

MISSING CASES = 7 OR 0.7 PCT.

Table C.12 Smoke yearly 98th percentile of daily values

Variable	MEAN	STD DEV	CASES
FOR ENTIRE POPULATION	62.3867	34.8500	1006
Open space	37.6937	24.0786	111
No smoke control	37.6937	24.0786	111
South east	31.8929	9.7005	28
Scotland	25.9286	16.0214	14
South West	23.0000	.0000	1
North West	41.4167	16.4618	12
North East	77.0833	40.7909	12
Northern Ireland	25.4000	6.3087	5
Midlands	48.7500	12.9894	20
Wales	17.2941	7.8483	17
East Anglia	43.5000	6.3640	2
Residential	62.6303	34.1218	376
No smoke control	65.7027	39.1767	222
South east	41.7333	13.4001	45
Scotland	53.4800	29.4295	25
South West	45.4545	15.7185	11
North West	75.3929	29.7189	28
North East	93.3571	54.5057	42
Northern Ireland	97.8000	53.6196	10
Midlands	68.9167	34.2615	36
Wales	53.9375	28.6297	16
East Anglia	56.5000	10.3296	6
London	59.3333	10.6927	3
Smoke control	58.2013	24.5616	154
South east	52.7273	18.4396	11
Scotland	75.1579	28.6555	19
South West	58.0000	5.6569	2
North West	56.1765	15.4772	34
North East	51.2619	31.9360	42
Northern Ireland	39.3333	20.3060	3
Midlands	58.2667	18.9377	15
Wales	79.0000	.0000	1
London	63.1481	17.9801	27

Table C.13 Smoke yearly 98th percentile of daily values - continued

Variable	MEAN	STD DEV	CASES
Commercial	64.4808	23.9210	52
No smoke control	62.7368	24.6798	19
South east	38.5000	13.4350	2
Scotland	79.0000	8.4853	2
South West	55.8000	10.8028	5
North West	69.0000	.0000	1
North East	111.0000	49.4975	2
Midlands	49.3333	12.0968	3
Wales	63.5000	14.8492	2
East Anglia	54.0000	.0000	1
London	58.0000	.0000	1
Smoke control	65.4848	23.8014	33
South east	68.3333	44.0606	3
Scotland	57.5000	50.2046	2
South West	65.0000	14.1421	2
North West	82.5000	34.1126	4
North East	68.0000	21.2446	7
Midlands	68.2000	23.4457	5
Wales	57.0000	.0000	1
East Anglia	30.0000	.0000	1
London	59.6250	4.3074	8
Industrial	54.4783	24.9251	23
No smoke control	51.8000	23.2370	20
South east	61.3333	31.2143	3
Scotland	14.0000	.0000	1
North West	50.7778	16.2001	9
North East	42.2500	11.1766	4
Midlands	105.0000	.0000	1
London	53.5000	30.4056	2
Smoke control	72.3333	33.9755	3
North East	110.0000	.0000	1
Midlands	44.0000	.0000	1
London	63.0000	.0000	1

Table C.14 Smoke yearly 98th percentile of daily values - continued

Variable	MEAN	STD DEV	CASES
Residential/industrial	72.5385	35.3436	221
No smoke control	77.0462	41.1232	130
South east	48.0000	14.2127	9
Scotland	82.2381	35.4794	21
South West	48.6000	12.4218	5
North West	72.7500	23.5273	16
North East	95.6129	49.5148	31
Northern Ireland	108.0000	65.0282	7
Midlands	73.7667	38.0070	30
Wales	45.4444	13.0299	9
East Anglia	54.0000	1.4142	2
Smoke control	66.0989	23.6286	91
South east	46.5000	9.1924	2
Scotland	68.3077	29.7080	13
North West	60.5000	13.8860	26
North East	68.6000	28.0595	25
Midlands	70.6250	27.7846	16
East Anglia	44.0000	.0000	1
London	71.5000	14.2628	8
Residential/commercial/industrial	64.5336	37.3304	223
No smoke control	64.3448	40.3418	174
South east	43.9583	13.9786	48
Scotland	67.9130	31.9060	23
South West	38.3333	14.3928	12
North West	95.0833	31.2772	12
North East	95.8667	61.6395	30
Northern Ireland	87.3333	40.4516	3
Midlands	69.5161	35.9888	31
Wales	41.0000	20.7934	12
East Anglia	46.0000	14.0000	3
Smoke control	65.2041	24.0615	49
South east	62.0000	21.2132	2
Scotland	78.0000	53.3573	3
South West	37.5000	2.1213	2
North West	60.5714	17.4520	14
North East	67.5385	23.0890	13
Northern Ireland	125.0000	.0000	1
Midlands	65.2500	21.7762	12
London	64.0000	8.4853	2

TOTAL CASES = 1013
MISSING CASES = 7 OR 0.7 PCT.

Table C.15 Sulphur dioxide winter median of daily values

Variable	MEAN	STD DEV	CASES
FOR ENTIRE POPULATION	42.3463	20.1539	999
Open space	28.7216	18.3931	97
No smoke control	28.7216	18.3931	97
South east	29.0000	13.6848	23
Scotland	16.0000	13.2514	11
South West	6.0000	.0000	1
North West	34.5714	15.2628	7
North East	45.1000	20.1464	10
Northern Ireland	19.0000	2.9439	4
Midlands	43.0952	15.7636	21
Wales	11.1111	7.7299	18
East Anglia	31.5000	2.1213	2
Residential	40.9021	19.3543	378
No smoke control	39.1937	18.3069	222
South east	35.2439	13.0782	41
Scotland	26.9565	12.5534	23
South West	32.0909	11.2912	11
North West	39.8571	15.9808	28
North East	47.5116	25.1039	43
Northern Ireland	37.0000	13.6582	12
Midlands	44.3514	20.0183	37
Wales	32.7059	10.8959	17
East Anglia	46.6667	9.1579	6
London	50.7500	4.7871	4
Smoke control	43.3333	20.5697	156
South east	46.5455	14.8483	11
Scotland	34.8947	11.7610	19
South West	39.6667	11.8462	3
North West	46.1765	15.9573	34
North East	33.0476	20.7093	42
Northern Ireland	17.6667	1.5275	3
Midlands	47.2143	13.6505	14
Wales	43.0000	.0000	1
London	60.3793	23.4177	29

Table C.16 Sulphur dioxide winter median of daily values - continued

Variable	MEAN	STD DEV	CASES
Commercial	50.6852	21.7593	54
No smoke control	44.5714	22.4468	21
South east	38.0000	11.3137	2
Scotland	46.5000	7.7782	2
South West	27.1667	4.2622	6
North West	32.0000	.0000	1
North East	68.5000	51.6188	2
Midlands	39.0000	22.8692	3
Wales	50.0000	16.9706	2
East Anglia	68.0000	.0000	1
London	75.0000	5.6569	2
Smoke control	54.5758	20.7154	33
South east	36.6667	15.1438	3
Scotland	44.5000	36.0624	2
South West	53.5000	14.8492	2
North West	66.5000	12.6886	4
North East	51.5714	19.5862	7
Midlands	46.6000	11.7175	5
Wales	41.0000	.0000	1
East Anglia	33.0000	.0000	1
London	70.1250	23.0430	8
Industrial	46.5263	22.3864	19
No smoke control	44.2500	20.4597	16
South east	40.3333	12.2202	3
Scotland	10.0000	.0000	1
North West	56.4286	14.5586	7
North East	28.2500	16.4798	4
London	69.0000	.0000	1
Smoke control	58.6667	33.2916	3
North East	42.0000	.0000	1
Midlands	37.0000	.0000	1
London	97.0000	.0000	1

Table C.17 Sulphur dioxide winter median of daily values - continued

Variable	MEAN	STD DEV	CASES
Residential/industrial	48.8496	19.2417	226
No smoke control	46.8815	19.1253	135
South east	50.6154	11.3691	13
Scotland	35.3333	13.0397	21
South West	29.0000	12.0623	5
North West	56.2941	15.0240	17
North East	55.9655	23.0488	29
Northern Ireland	28.5714	6.0788	7
Midlands	52.1667	16.5531	30
Wales	31.1818	14.8514	11
East Anglia	48.0000	15.5563	2
Smoke control	51.7692	19.1463	91
South east	48.5000	19.0919	2
Scotland	39.5833	11.9655	12
North West	53.6429	13.8141	28
North East	44.5417	18.3041	24
Midlands	61.0667	24.3940	15
East Anglia	43.0000	.0000	1
London	67.6667	19.5576	9
Residential/commercial/industrial	41.7600	19.1021	225
No smoke control	39.7457	19.0136	173
South east	35.4490	12.9439	49
Scotland	28.7143	6.4354	21
South West	27.2000	15.2592	10
North West	45.4167	18.7299	12
North East	55.0645	22.5417	31
Northern Ireland	23.5000	3.6968	4
Midlands	45.0000	20.2008	29
Wales	33.1429	18.4134	14
East Anglia	49.6667	19.7569	3
Smoke control	48.4615	17.9961	52
South east	28.0000	14.1421	2
Scotland	17.5000	3.5355	2
South West	46.0000	.0000	1
North West	54.2500	12.9949	16
North East	41.0714	18.6443	14
Northern Ireland	28.0000	.0000	1
Midlands	53.0909	14.5633	11
London	65.6000	15.3883	5

TOTAL CASES = 1006

399

MISSING CASES = 7 OR 0.7 PCT.

Table C.18 Sulphur dioxide yearly arithmetic mean values

Variable	MEAN	STD DEV	CASES
FOR ENTIRE POPULATION	45.5905	18.6820	989
Open space	33.6095	18.4680	105
No smoke control	33.6095	18.4680	105
South east	33.8148	15.3022	27
Scotland	21.8182	12.2623	11
South West	10.0000	.0000	1
North West	39.1818	24.1695	11
North East	50.3636	16.8836	11
Northern Ireland	24.0000	2.8284	5
Midlands	46.6000	13.4884	20
Wales	15.5882	7.1419	17
East Anglia	32.0000	1.4142	2
Residential	44.5389	17.4675	373
No smoke control	42.6955	16.8657	220
South east	38.9778	13.0497	45
Scotland	30.0000	11.6930	23
South West	32.5455	8.6529	11
North West	46.1429	17.3754	28
North East	50.7143	21.6764	42
Northern Ireland	39.4000	13.0571	10
Midlands	47.9444	16.5408	36
Wales	38.5625	11.1114	16
East Anglia	43.8333	6.7651	6
London	56.3333	1.1547	3
Smoke control	47.1895	18.0251	153
South east	47.8182	11.1787	11
Scotland	39.7368	9.7174	19
South West	38.0000	12.7279	2
North West	52.0588	14.4410	34
North East	38.7857	20.7124	42
Northern Ireland	20.6667	.5774	3
Midlands	52.4286	17.2302	14
Wales	42.0000	.0000	1
London	60.2222	14.9803	27

Table C.19 Sulphur dioxide yearly arithmetic mean values - continued

Variable	MEAN	STD DEV	CASES
Commercial	53.1538	20.1838	52
No smoke control	45.8421	18.5660	19
South east	43.5000	9.1924	2
Scotland	48.5000	13.4350	2
South West	30.4000	5.4129	5
North West	39.0000	.0000	1
North East	63.5000	40.3051	2
Midlands	42.0000	18.1934	3
Wales	53.0000	21.2132	2
East Anglia	65.0000	.0000	1
London	72.0000	.0000	1
Smoke control	57.3636	20.1336	33
South east	37.6667	15.9478	3
Scotland	48.0000	35.3553	2
South West	56.5000	10.6066	2
North West	69.0000	14.0238	4
North East	54.8571	18.1882	7
Midlands	52.0000	11.4455	5
Wales	37.0000	.0000	1
East Anglia	47.0000	.0000	1
London	70.8750	23.7513	8
Industrial	48.7273	18.7418	22
No smoke control	47.3158	17.7296	19
South east	44.0000	11.7898	3
Scotland	16.0000	.0000	1
North West	57.6250	12.7720	8
North East	31.2500	17.9884	4
Midlands	47.0000	.0000	1
London	59.0000	9.8995	2
Smoke control	57.6667	26.8390	3
North East	48.0000	.0000	1
Midlands	37.0000	.0000	1
London	88.0000	.0000	1

Table C.20 Sulphur dioxide yearly arithmetic mean values - continued

Variable	MEAN	STD DEV	CASES
Residential/industrial	51.6806	16.9806	216
No smoke control	49.8492	16.7543	126
South east	48.0000	8.9283	8
Scotland	40.8000	15.5177	20
South West	30.8000	8.8713	5
North West	56.8125	12.2214	16
North East	57.8710	18.8180	31
Northern Ireland	31.1429	6.7929	7
Midlands	54.9643	14.4234	28
Wales	41.3333	8.4113	9
East Anglia	47.5000	14.8492	2
Smoke control	54.2444	17.0560	90
South east	48.0000	22.6274	2
Scotland	42.3846	11.4057	13
North West	55.9615	10.9306	26
North East	49.3750	19.2576	24
Midlands	62.0000	18.3303	16
East Anglia	42.0000	.0000	1
London	70.1250	15.0184	8
Residential/commercial/industrial	45.0136	18.9433	221
No smoke control	43.2674	18.7154	172
South east	38.4792	13.1715	48
Scotland	31.6957	9.6127	23
South West	29.2500	12.7288	12
North West	53.0000	17.4981	12
North East	58.9333	18.5972	30
Northern Ireland	24.0000	4.5826	3
Midlands	49.8276	19.8406	29
Wales	38.6667	22.3050	12
East Anglia	43.3333	13.0128	3
Smoke control	51.1429	18.6447	49
South east	29.0000	15.5563	2
Scotland	23.0000	4.5826	3
South West	45.0000	.0000	2
North West	62.4286	14.0752	14
North East	45.7692	16.5033	13
Northern Ireland	29.0000	.0000	1
Midlands	53.5000	15.8831	12
London	74.5000	23.3345	2

TOTAL CASES = 996

402

MISSING CASES = 7 OR 0.7 PCT.

Table C.21 Sulphur dioxide yearly median values

Variable	MEAN	STD DEV	CASES
FOR ENTIRE POPULATION	40.4419	17.5048	989
Open space	29.3143	16.5908	105
No smoke control	29.3143	16.5908	105
South east	29.9630	14.0835	27
Scotland	18.6364	13.3587	11
South West	6.0000	.0000	1
North West	30.5455	12.9951	11
North East	45.8182	16.2654	11
Northern Ireland	22.2000	2.1679	5
Midlands	42.0000	13.4125	20
Wales	12.2353	6.4278	17
East Anglia	29.5000	.7071	2
Residential	39.3137	16.5750	373
No smoke control	37.7091	16.0310	220
South east	34.7333	12.4980	45
Scotland	27.1304	11.4507	23
South West	27.6364	6.4230	11
North West	39.8929	17.0497	28
North East	44.5476	21.0066	42
Northern Ireland	34.4000	11.6447	10
Midlands	43.0278	16.2595	36
Wales	33.3750	9.8582	16
East Anglia	41.5000	7.3959	6
London	47.0000	1.7321	3
Smoke control	41.6209	17.1176	153
South east	43.4545	11.5876	11
Scotland	35.3684	9.0444	19
South West	31.5000	14.8492	2
North West	46.3529	14.3229	34
North East	33.3810	18.2168	42
Northern Ireland	17.6667	1.5275	3
Midlands	46.2143	15.9382	14
Wales	38.0000	.0000	1
London	53.2963	16.9973	27

Table C.22 Sulphur dioxide yearly median values - continued

Variable	MEAN	STD DEV	CASES
Commercial	47.7115	18.8121	52
No smoke control	41.4211	18.1209	19
South east	36.0000	5.6569	2
Scotland	43.5000	10.6066	2
South West	27.2000	5.3572	5
North West	37.0000	.0000	1
North East	59.0000	36.7696	2
Midlands	35.6667	21.0792	3
Wales	50.5000	19.0919	2
East Anglia	64.0000	.0000	1
London	65.0000	.0000	1
Smoke control	51.3333	18.5011	33
South east	34.3333	17.2143	3
Scotland	43.0000	32.5269	2
South West	53.5000	7.7782	2
North West	61.2500	10.9659	4
North East	50.0000	16.4418	7
Midlands	45.8000	10.8490	5
Wales	33.0000	.0000	1
East Anglia	40.0000	.0000	1
London	62.6250	23.0833	8
Industrial	43.0455	19.1199	22
No smoke control	41.5263	17.4017	19
South east	40.3333	12.2202	3
Scotland	8.0000	.0000	1
North West	50.0000	14.2227	8
North East	27.0000	15.1217	4
Midlands	41.0000	.0000	1
London	55.5000	10.6066	2
Smoke control	52.6667	30.8599	3
North East	39.0000	.0000	1
Midlands	31.0000	.0000	1
London	88.0000	.0000	1

Table C.23 Sulphur dioxide yearly median values - continued

Variable	MEAN	STD DEV	CASES
Residential/industrial	45.9537	15.8557	216
No smoke control	44.3651	15.7173	126
South east	43.3750	8.6179	8
Scotland	37.2500	14.8249	20
South West	26.4000	8.8769	5
North West	50.9375	10.1026	16
North East	51.2258	18.1635	31
Northern Ireland	27.2857	5.8797	7
Midlands	48.5714	14.4207	28
Wales	36.2222	7.8705	9
East Anglia	43.0000	14.1421	2
Smoke control	48.1778	15.8678	90
South east	39.0000	16.9706	2
Scotland	37.5385	10.9210	13
North West	50.4615	11.1040	26
North East	43.6667	17.3723	24
Midlands	55.0000	18.3739	16
East Anglia	37.0000	.0000	1
London	61.6250	12.0823	8
Residential/commercial/industrial	40.2760	17.7349	221
No smoke control	38.7267	17.5229	172
South east	33.8542	12.1112	48
Scotland	28.6087	8.7788	23
South West	26.5000	10.1310	12
North West	47.5833	16.9784	12
North East	52.4000	18.2787	30
Northern Ireland	23.0000	5.0000	3
Midlands	44.5862	18.9784	29
Wales	35.9167	22.5367	12
East Anglia	41.3333	16.0416	3
Smoke control	45.7143	17.5760	49
South east	27.5000	13.4350	2
Scotland	20.6667	4.6188	3
South West	39.0000	1.4142	2
North West	56.6429	13.3855	14
North East	39.2308	15.8227	13
Northern Ireland	26.0000	.0000	1
Midlands	48.7500	15.3393	12
London	65.5000	23.3345	2

TOTAL CASES = 996
MISSING CASES = 7 OR 0.7 PCT.

Table C.24 Sulphur dioxide yearly 98th percentile values

Variable	MEAN	STD DEV	CASES
FOR ENTIRE POPULATION	113.0121	45.7087	989
Open space	86.4952	44.8819	105
No smoke control	86.4952	44.8819	105
South east	89.6667	41.0150	27
Scotland	65.4545	21.7548	11
South West	32.0000	.0000	1
North West	114.4545	78.5040	11
North East	116.4545	38.4587	11
Northern Ireland	59.0000	5.9582	5
Midlands	108.0000	23.3216	20
Wales	44.6471	16.8521	17
East Anglia	77.5000	6.3640	2
Residential	112.4182	46.1332	373
No smoke control	106.2818	42.8886	220
South east	96.7556	32.9146	45
Scotland	69.0870	26.4677	23
South West	88.6364	31.7562	11
North West	121.4643	41.5892	28
North East	129.7857	55.1072	42
Northern Ireland	106.9000	38.9457	10
Midlands	111.8889	38.7289	36
Wales	92.9375	23.0723	16
East Anglia	91.6667	17.0489	6
London	159.3333	9.5044	3
Smoke control	121.2418	49.2500	153
South east	111.7273	19.0897	11
Scotland	105.2105	30.1230	19
South West	156.0000	38.1838	2
North West	126.2941	33.6880	34
North East	111.7381	73.7789	42
Northern Ireland	58.0000	10.0000	3
Midlands	122.4286	33.9858	14
Wales	107.0000	.0000	1
London	149.1852	31.1004	27

Table C.25 Sulphur dioxide yearly 98th percentile values - continued

Variable	MEAN	STD DEV	CASES
Commercial	127.2885	48.8019	52
No smoke control	106.8947	41.9866	19
South east	121.0000	41.0122	2
Scotland	108.5000	50.2046	2
South West	69.8000	7.8549	5
North West	87.0000	.0000	1
North East	128.0000	76.3675	2
Midlands	107.6667	19.7569	3
Wales	107.5000	13.4350	2
East Anglia	128.0000	.0000	1
London	214.0000	.0000	1
Smoke control	139.0303	49.1423	33
South east	98.3333	39.7031	3
Scotland	101.0000	66.4680	2
South West	129.0000	42.4264	2
North West	150.7500	36.3077	4
North East	131.4286	47.9891	7
Midlands	126.0000	25.9904	5
Wales	96.0000	.0000	1
East Anglia	101.0000	.0000	1
London	185.3750	49.4077	8
Industrial	124.7273	45.4692	22
No smoke control	123.6842	48.2667	19
South east	106.3333	19.6554	3
Scotland	74.0000	.0000	1
North West	152.3750	51.3891	8
North East	90.0000	50.2062	4
Midlands	106.0000	.0000	1
London	136.0000	1.4142	2
Smoke control	131.3333	25.7941	3
North East	124.0000	.0000	1
Midlands	110.0000	.0000	1
London	160.0000	.0000	1

Table C.26 Sulphur dioxide yearly 98th percentile values - continued

Variable	MEAN	STD DEV	CASES
Residential/industrial	125.8611	41.5844	216
No smoke control	121.6984	42.0225	126
South east	109.5000	22.9658	8
Scotland	97.6500	37.7168	20
South West	79.4000	14.4326	5
North West	135.5000	35.7305	16
North East	145.3548	50.1182	31
Northern Ireland	77.5714	17.9151	7
Midlands	133.5357	30.5038	28
Wales	105.8889	23.6561	9
East Anglia	99.5000	16.2635	2
Smoke control	131.6889	40.4768	90
South east	137.0000	49.4975	2
Scotland	106.0000	34.0465	13
North West	129.1154	25.0684	26
North East	125.6667	49.7215	24
Midlands	148.9375	30.7581	16
East Anglia	76.0000	.0000	1
London	171.0000	42.7451	8
Residential/commercial/industrial	109.5294	42.6616	221
No smoke control	105.6686	42.7784	172
South east	98.0833	32.2120	48
Scotland	80.7826	24.8741	23
South West	76.0000	42.8464	12
North West	118.3333	42.8068	12
North East	144.7333	38.5942	30
Northern Ireland	47.0000	16.0935	3
Midlands	119.0690	41.4039	29
Wales	88.7500	46.3016	12
East Anglia	92.0000	7.0000	3
Smoke control	123.0816	39.7680	49
South east	67.5000	37.4767	2
Scotland	67.0000	19.3132	3
South West	114.5000	13.4350	2
North West	138.3571	33.2649	14
North East	121.3077	32.6328	13
Northern Ireland	94.0000	.0000	1
Midlands	121.9167	33.2059	12
London	197.5000	57.2756	2

TOTAL CASES = 996
MISSING CASES = 7 OR 0.7 PCT.

Table C.27 $\frac{\text{smoke}}{\text{SO}_2}$ winter median of daily values

Variable	MEAN	STD DEV	CASES
FOR ENTIRE POPULATION	.4735	.4301	995
Open space	.5037	.8375	95
No smoke control	.5037	.8375	95
South east	.5712	1.2223	22
Scotland	.5150	.1588	11
South West	.1667	.0000	1
North West	.3463	.1054	7
North East	.4662	.1790	10
Northern Ireland	.3369	.0738	4
Midlands	.3326	.1385	20
Wales	.7542	1.3572	18
East Anglia	.3955	.0407	2
Residential	.4788	.4404	377
No smoke control	.5320	.5320	221
South east	.4967	1.0550	41
Scotland	.5514	.2130	22
South West	.3211	.1390	11
North West	.5924	.3079	28
North East	.6322	.3028	43
Northern Ireland	.8024	.6391	12
Midlands	.4508	.1860	37
Wales	.4649	.3325	17
East Anglia	.4026	.1068	6
London	.2895	.0737	4
Smoke control	.4034	.2429	156
South east	.2921	.1180	11
Scotland	.4689	.2160	19
South West	.3055	.2684	3
North West	.3630	.1437	34
North East	.4816	.3659	42
Northern Ireland	.6626	.3033	3
Midlands	.3806	.1137	14
Wales	.4186	.0000	1
London	.3307	.1440	29

Table C.28 $\frac{\text{smoke}}{\text{SO}_2}$ winter median of daily values - continued

Variable	MEAN	STD DEV	CASES
Commercial	.4072	.2209	54
No smoke control	.4513	.2709	21
South east	.2413	.0584	2
Scotland	.6166	.3008	2
South West	.4964	.0995	6
North West	.6563	.0000	1
North East	.7515	.7934	2
Midlands	.4173	.1710	3
Wales	.3812	.2425	2
East Anglia	.2059	.0000	1
London	.2013	.0340	2
Smoke control	.3792	.1813	33
South east	.5373	.1616	3
Scotland	.3244	.0867	2
South West	.2411	.0537	2
North West	.3825	.1794	4
North East	.4180	.2205	7
Midlands	.4912	.2461	5
Wales	.4390	.0000	1
East Anglia	.3939	.0000	1
London	.2532	.0717	8
Industrial	.3948	.1940	18
No smoke control	.3941	.1875	15
South east	.4618	.2276	3
North West	.3211	.1569	7
North East	.4681	.2365	4
London	.4058	.0000	1
Smoke control	.3986	.2715	3
North East	.6667	.0000	1
Midlands	.4054	.0000	1
London	.1237	.0000	1

Table C.29 $\frac{\text{smoke}}{\text{SO}_2}$ winter median of daily values - continued

Variable	MEAN	STD DEV	CASES
Residential/industrial	.4662	.2854	226
No smoke control	.5224	.3252	135
South east	.2688	.0574	13
Scotland	.6595	.2890	21
South West	.3790	.1377	5
North West	.4096	.1219	17
North East	.5330	.2075	29
Northern Ireland	1.2204	.8636	7
Midlands	.4686	.1614	30
Wales	.5055	.2434	11
East Anglia	.3552	.0709	2
Smoke control	.3826	.1856	91
South east	.3048	.1346	2
Scotland	.4687	.1553	12
North West	.3386	.1385	28
North East	.4346	.2598	24
Midlands	.3518	.1550	15
East Anglia	.3256	.0000	1
London	.3416	.1398	9
Residential/commercial/industrial	.4812	.3203	225
No smoke control	.5002	.3392	173
South east	.3774	.1596	49
Scotland	.6948	.3839	21
South West	.3377	.1041	10
North West	.6442	.3282	12
North East	.4981	.2576	31
Northern Ireland	1.1092	.6175	4
Midlands	.5510	.4949	29
Wales	.3857	.1807	14
East Anglia	.3645	.1902	3
Smoke control	.4180	.2393	52
South east	.6579	.4838	2
Scotland	.9583	.1532	2
South West	.0870	.0000	1
North West	.3327	.1523	16
North East	.4575	.2231	14
Northern Ireland	1.1071	.0000	1
Midlands	.3799	.1066	11
London	.2808	.0769	5

411

TOTAL CASES = 1002

MISSING CASES = 7 OR 0.7 PCT.